BENTON HARBOR POWER PLANT LIMNOLOGICAL STUDIES

PART IV COOK PLANT PREOPERATIONAL STUDIES, 1969

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Great Lakes Research Division
The University of Michigan
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THERMAL PLUME STUDIES

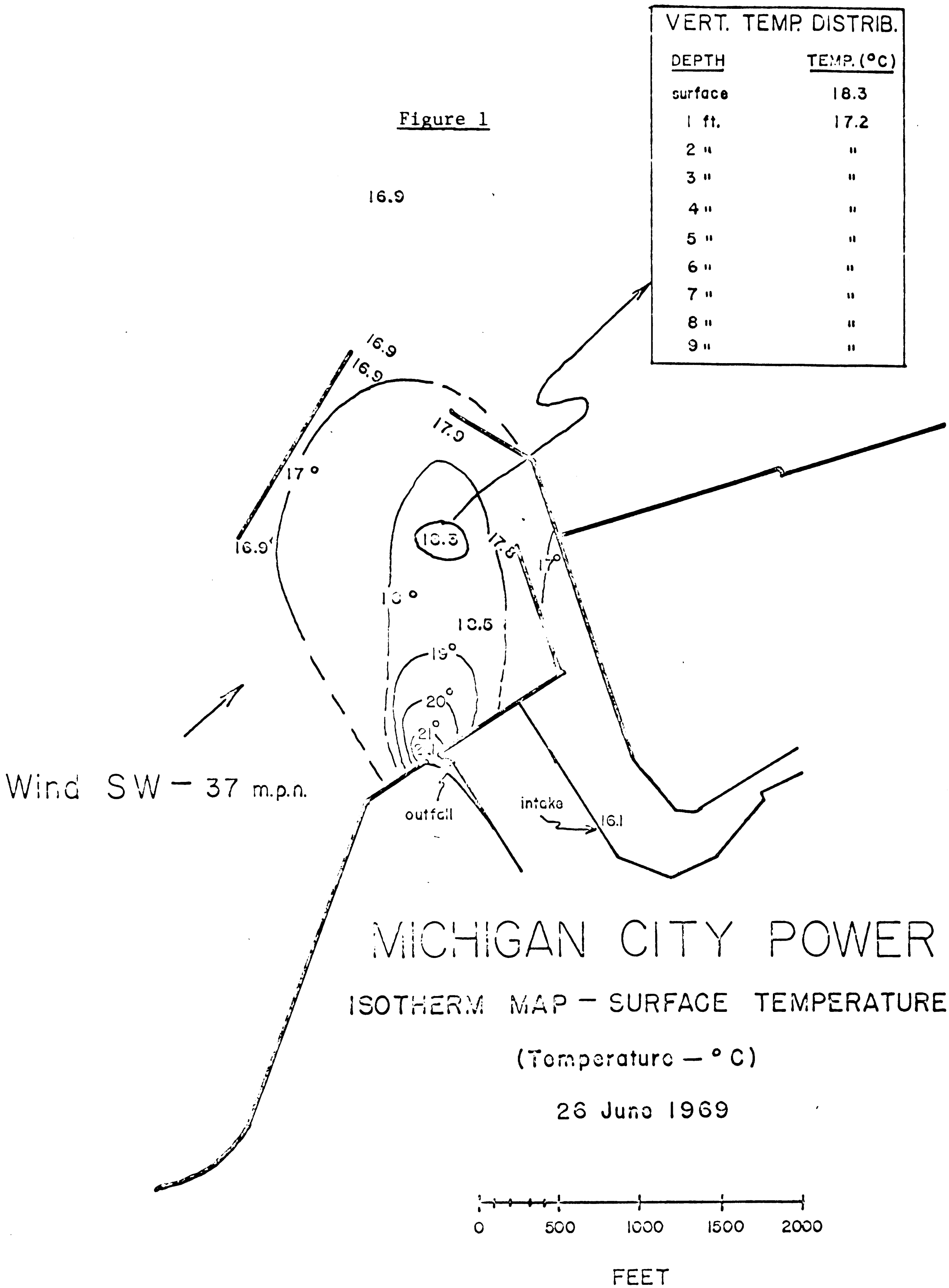
Michigan City, Indiana, Higher Wind

On 26 June 1969 the R/V MYSIS arrived in Michigan City during the beginning of a major blow from the southwest. Increasing strong southwest winds had blown for several hours before our arrival at Michigan City. During the time we had available to investigate the plume of the Michigan City Generating Station, wind speed was 37-40 mph. Although we were unfamiliar with the area and had problems in fighting the direct push of wind on the ship's hull and superstructure the situation was favorable for a survey of the generating plant's plume under higher wind conditions. Because the southwest wind was offshore, there was so little fetch that wave action was small. We believe that Michigan City, on this day, gave us an almost pure measure of the effect of wind ventilation alone on the dimensions of the warm-water plume from the Michigan City plant.

A thermistor, trailing from the ship's 10-foot long bowsprit in the surface water just ahead of the ship's bow wave, was the day's primary exploration instrument.

The surface temperature conditions, so far as we were able to survey them in the daylight remaining and under the difficult ship-handling conditions, are presented in Figure 1. In one position in nine feet of water we were able, by steaming into the wind, to get a chain of thermistors (cross-calibrated against the bowsprit thermistor) to descend vertically for sufficient time to obtain a vertical temperature profile. This was tried at other positions along the breakwalls, but the combination of windage on the ship and water-currents off the breakwalls prevented our obtaining vertical lowerings of the thermistor chain. Intake (whose location we did not then know) and outfall (which we could not reach) water temperatures for this day were kindly provided by Mr. E. L. Mann, Manager of Plant Engineering of the Michigan City plant, to whom our formal

Figure 1



VERT. TEMP. DISTRIB.
DEPTH TEMP. (°C)
surface 18.3
1 ft. 17.2
2 " "
3 " "
4 " "
5 " "
6 " "
7 " "
8 " "
9 " "
16.9
16.9
16.9
17.9
17°
16.9
17.8
17°
19°
20°
21°
outfall
intake
16.1
Wind SW – 37 m.p.h.
MICHIGAN CITY POWER
ISOTHERM MAP – SURFACE TEMPERATURE
(Temperature – °C)
26 June 1969
0 500 1000 1500 2000
FEET

thanks are tendered.

On this day, with wind fluctuating between 37 and 40 mph, the waste heat contributed by the Michigan City Generating Station was almost completely lost within the harbor breakwalls. The data later indicated that there may have been a leakage of about 0.9°C around the outer end of the east breakwall.

At the one station within the axis of the plume, as well as we could determine, the temperature of the water ranged from 18.3°C at the surface to 17.2° at one foot and stayed isothermal at 17.2° from there to the bottom at nine feet.

In about 2,200 feet from the outfall mouth to the outer end of the east breakwall the plume had fallen from 21.1° to 17.9°, a loss of 3.2°/4.2° or 76% of the excess heat (over 16.9° ambient) added by the Michigan City Generating Station. The area between the two outermost surface isotherms of the plume (18° to 17°) occupied more than half of the total demonstrable surface area of the plume.

Michigan City, Indiana, Light Wind

During 28 June 1969, after the passing of the major blow from the southwest, we again surveyed the plume of the Michigan City Generating Station under quite steady winds of 2 mph from the west-southwest. By renting a skiff and an outboard motor from a local marina we were able to occupy six shallow-water stations in and around the outfall channel mouth of the Michigan City plant. Stations in greater depth were taken directly from the R/V MYSIS.

The day was clear, quiet, and hot and the movement of water current was from the southwest primarily under the influence of the strong southwest wind of the day before.

The trailing bowsprit thermistor was again the primary instrument for determining whether we were in or out of the plume, but all station data were taken with a thermistor chain of one-foot spacing. Navigation was by sextant fixes to landmarks ashore.

The stations occupied on the 28th are shown in Figure 2. Station MCP-10 was set well off to windward to sample the ambient inshore lake water coming into the vicinity of the plant outfall. Temperature there was 21.0°C at the surface. On this day the intake temperature was 18.0°C and the temperature at the mouth of the outfall channel was 25.2°. Deterioration of surface temperature was rapid; at about the mid-length of the harbor temperatures ranged from 19.8° to 22.4°.

By comparison to the surface temperature at Station MCP-10, Stations MCP-12 and 14 probably had no heat contribution from the plant plume while Station MCP-13 at 4000 feet from the outfall appears to have had 0.5°C in the upper one foot remaining from the plant plume. This represents 0.5/7.2 or 7% of the heat added by the plant; the other 93% having been lost in 4000 feet.

The surface isotherms are plotted in Figure 3 and in Figures 4 through 11 are plotted the subsurface isotherms observed at each foot of depth. Depths and temperatures for each station also are tabulated in Table 1. Stations drop out of these maps when water depth becomes less than the depth being plotted. Water temperatures in the vertical diminished rapidly with increase of depth, and by eight feet the temperature condition in the harbor was probably an effect of the river outflow rather than an effect of the plant plume.

Biological samples as follows were collected from the Michigan City plume and its environs:

Phytoplankton: Station MCP-16 in the intake, Station MCP-1 in the outfall mouth, Station MCP-3 in the axis of the plume about 400 feet from the outfall mouth, and Station MCP-8 slightly outside the axis of the plume at about a thousand feet from the outfall mouth.

Figure 2

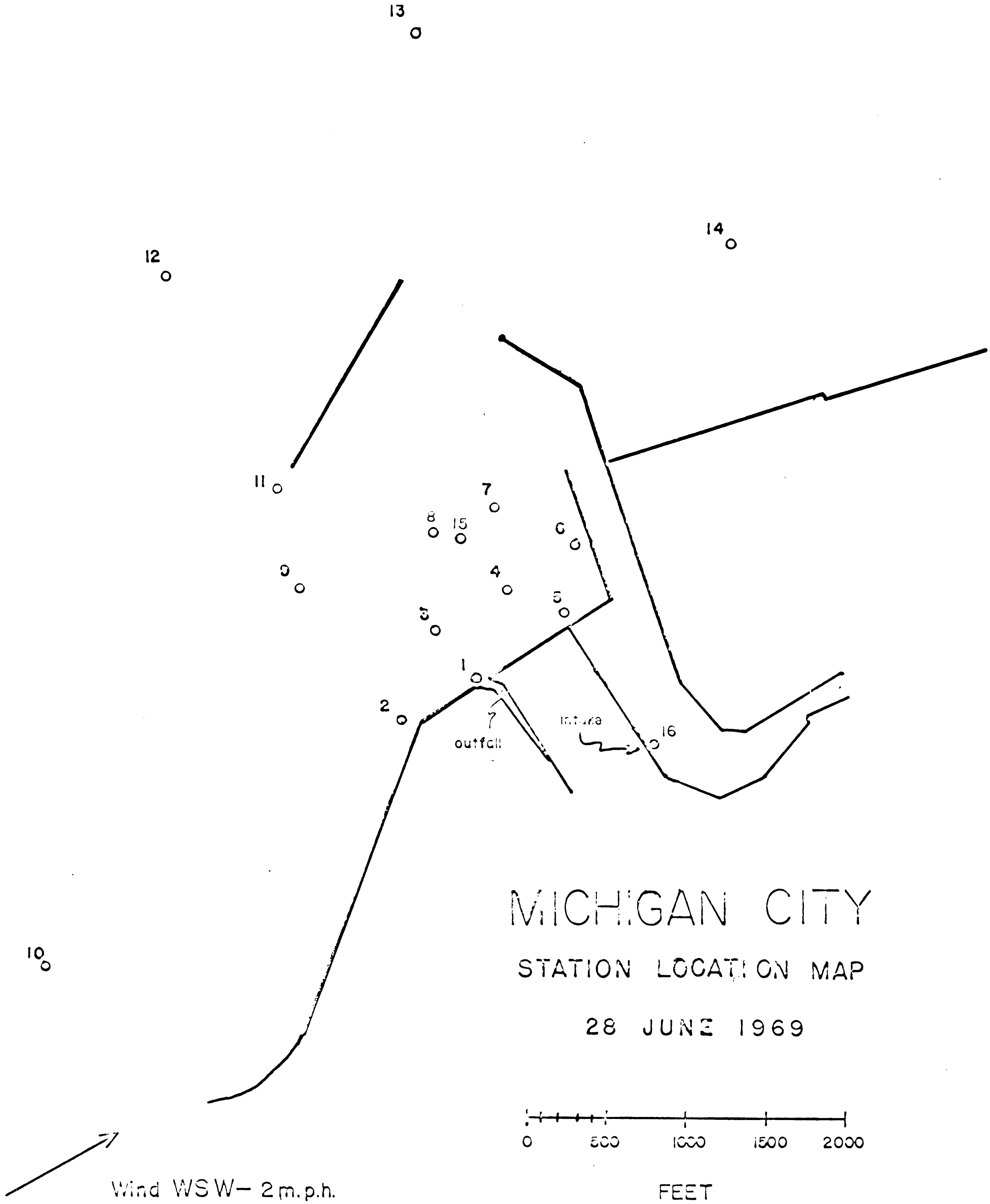

13
14
12
11
7
8
15
6
9
4
5
3
1
2
outfall
intake
16
10
MICHIGAN CITY
STATION LOCATION MAP
28 JUNE 1969
0
500
1000
1500
2000
FEET
Wind WSW– 2 m.p.h.

Figure 3

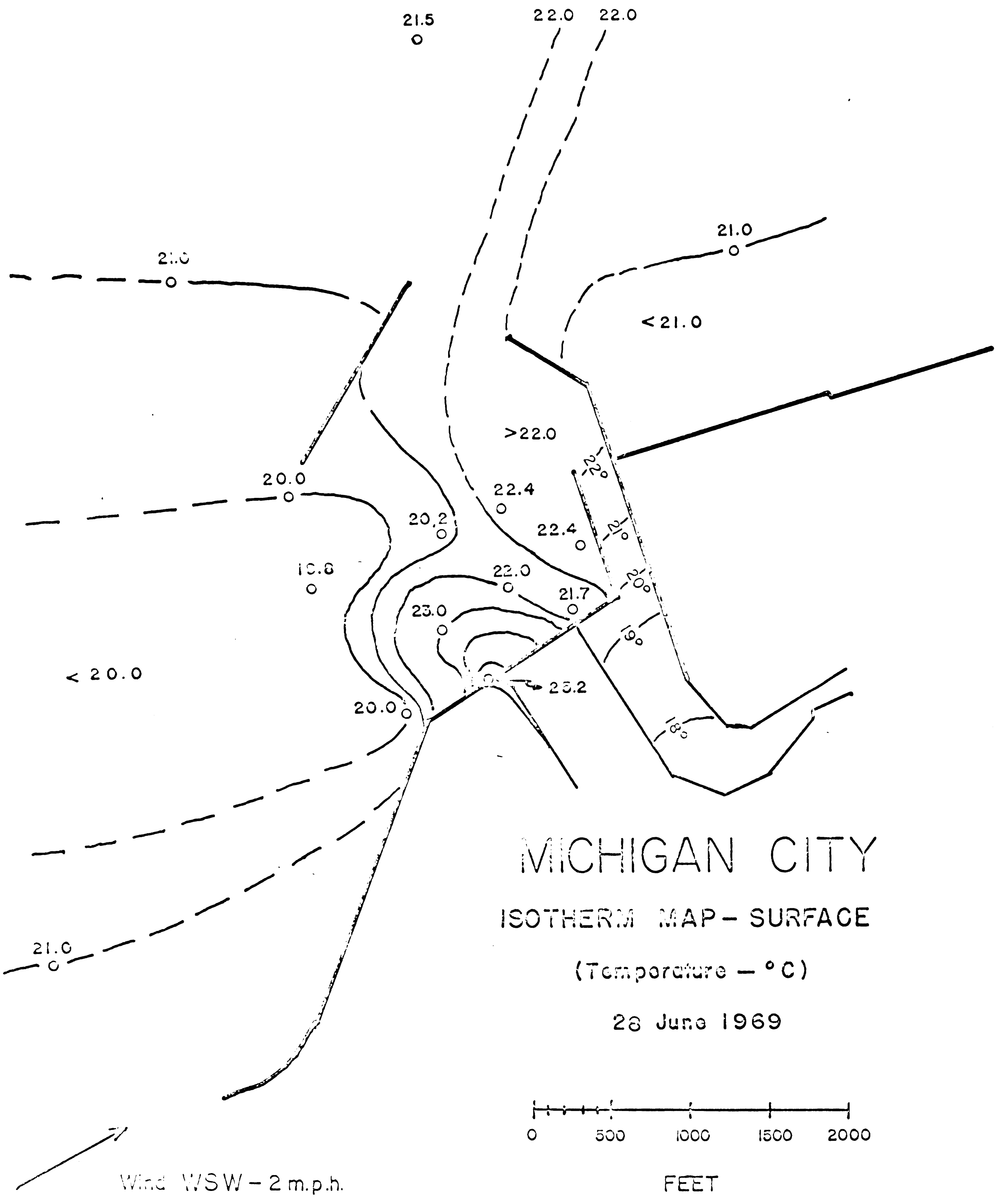

21.5
22.0
22.0
21.0
<21.0
>22.0
20.0
22.4
20.2
22.4
22°
21°
20°
19°
18°
22.0
21.7
23.0
< 20.0
20.0
21.0
MICHIGAN CITY
ISOTHERM MAP - SURFACE
(Temperature — °C)
28 June 1969
0
500
1000
1500
2000
FEET
Wind WSW - 2 m.p.h.

Figure 4

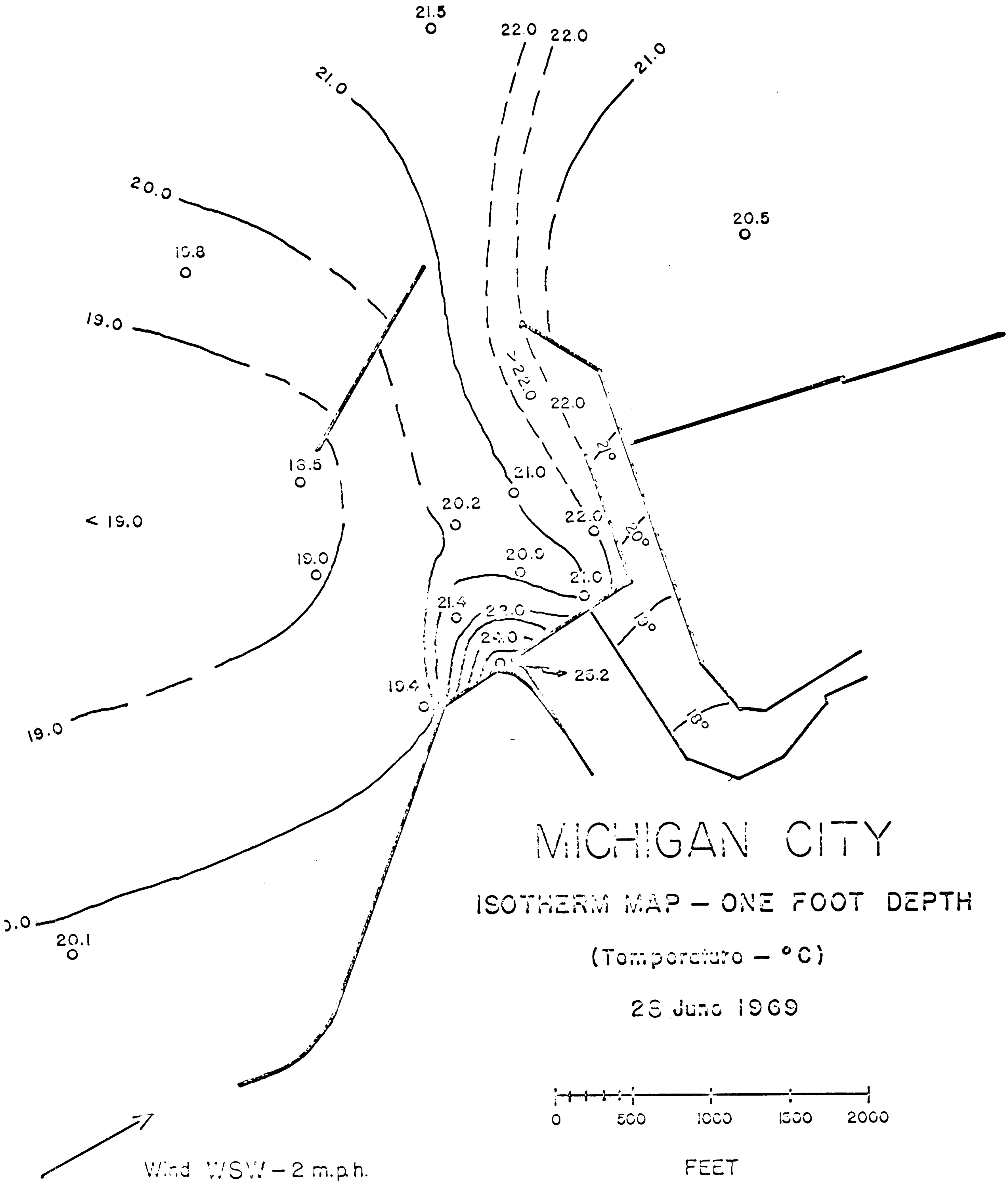

MICHIGAN CITY
ISOTHERM MAP – ONE FOOT DEPTH
(Temperature – °C)
28 June 1969
0
500
1000
1500
2000
FEET
Wind WSW – 2 m.p.h.
21.5
22.0
22.0
21.0
21.0
20.0
20.5
19.0
< 19.0
20.2
20.1
19.4
21.4
24.0
25.2
22.0
21.0

Figure 5

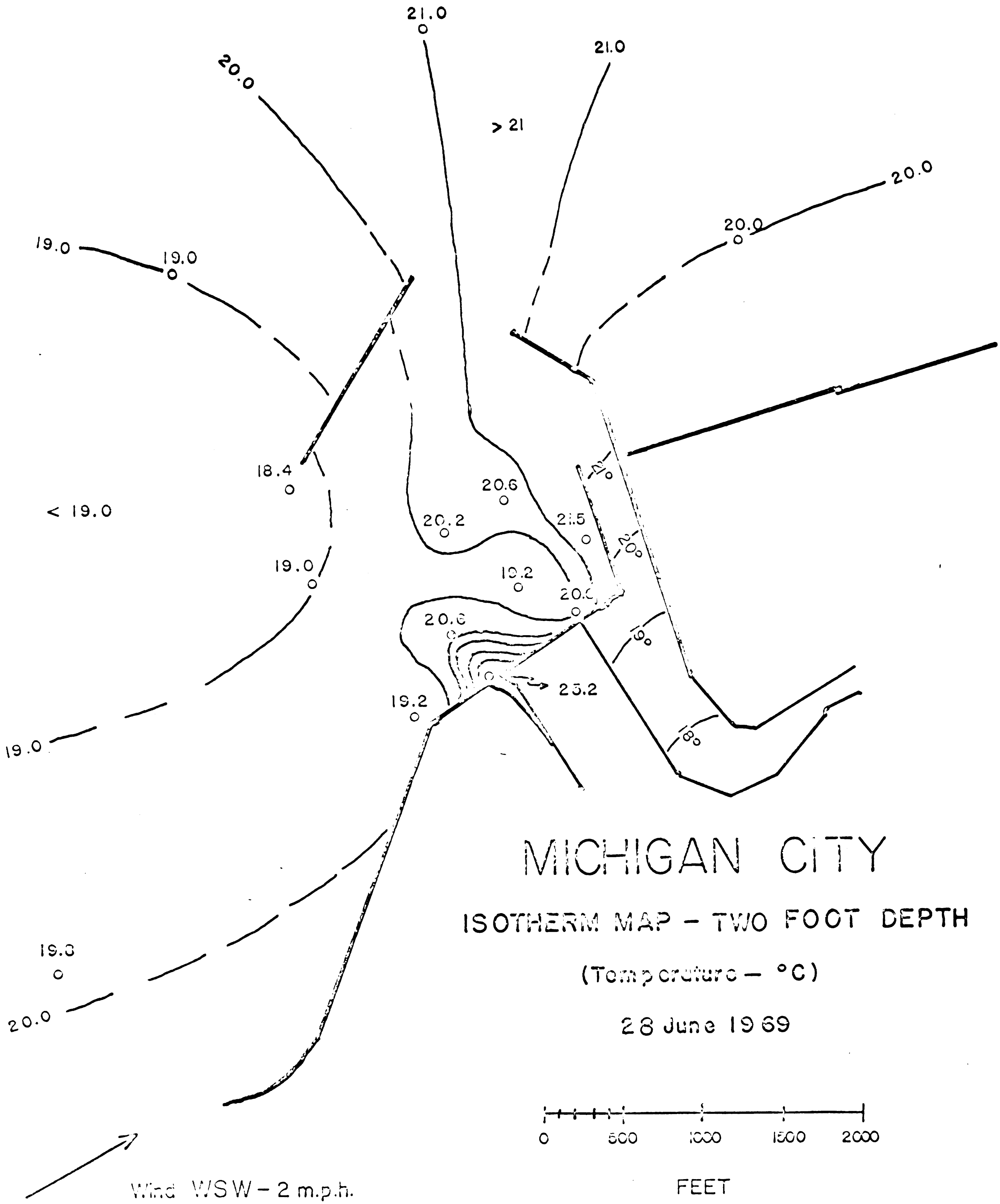

MICHIGAN CITY
ISOTHERM MAP - TWO FOOT DEPTH
(Temperature - °C)
28 June 1969
21.0
21.0
20.0
> 21
20.0
20.0
19.0
19.0
18.4
< 19.0
19.0
20.6
20.2
21.5
19.2
20.6
19.2
19.0
19.3
20.0
0
500
1000
1500
2000
FEET
Wind WSW - 2 m.p.h.

Figure 6

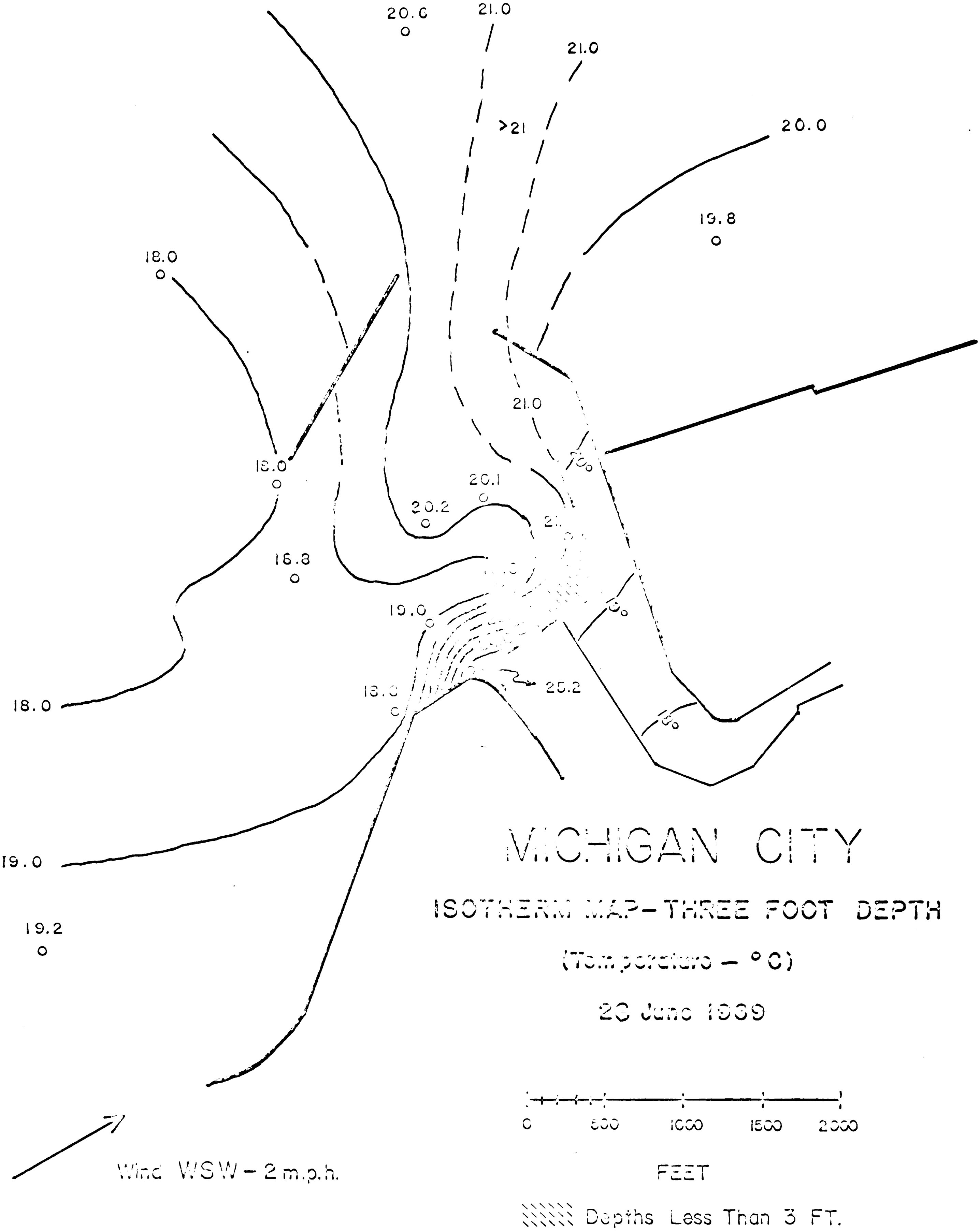

MICHIGAN CITY
ISOTHERM MAP - THREE FOOT DEPTH
(Temperature - °C)
21.0
21.0
>21
20.0
19.8
18.0
21.0
20.1
20.2
16.8
25.2
18.0
19.0
19.2
0
500
1000
1500
2000
FEET
Depths Less Than 3 FT.
Wind WSW - 2 m.p.h.

Figure 7

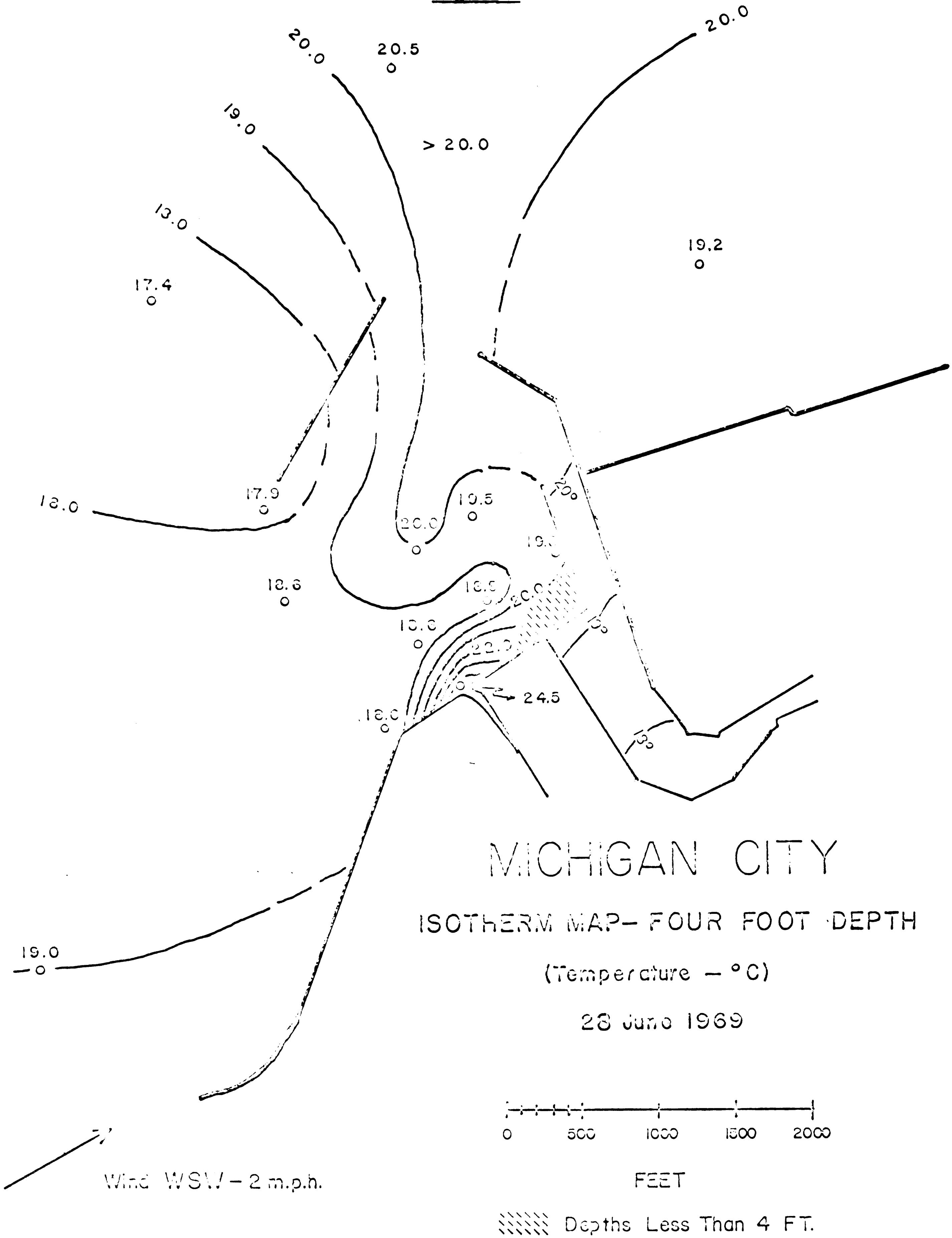

20.0
20.5
20.0
> 20.0
19.0
19.2
17.4
17.9
19.5
24.5
19.0
MICHIGAN CITY
ISOTHERM MAP- FOUR FOOT DEPTH
(Temperature – °C)
28 June 1969
0
500
1000
1500
2000
FEET
Wind WSW – 2 m.p.h.
Depths Less Than 4 FT.

Figure 8

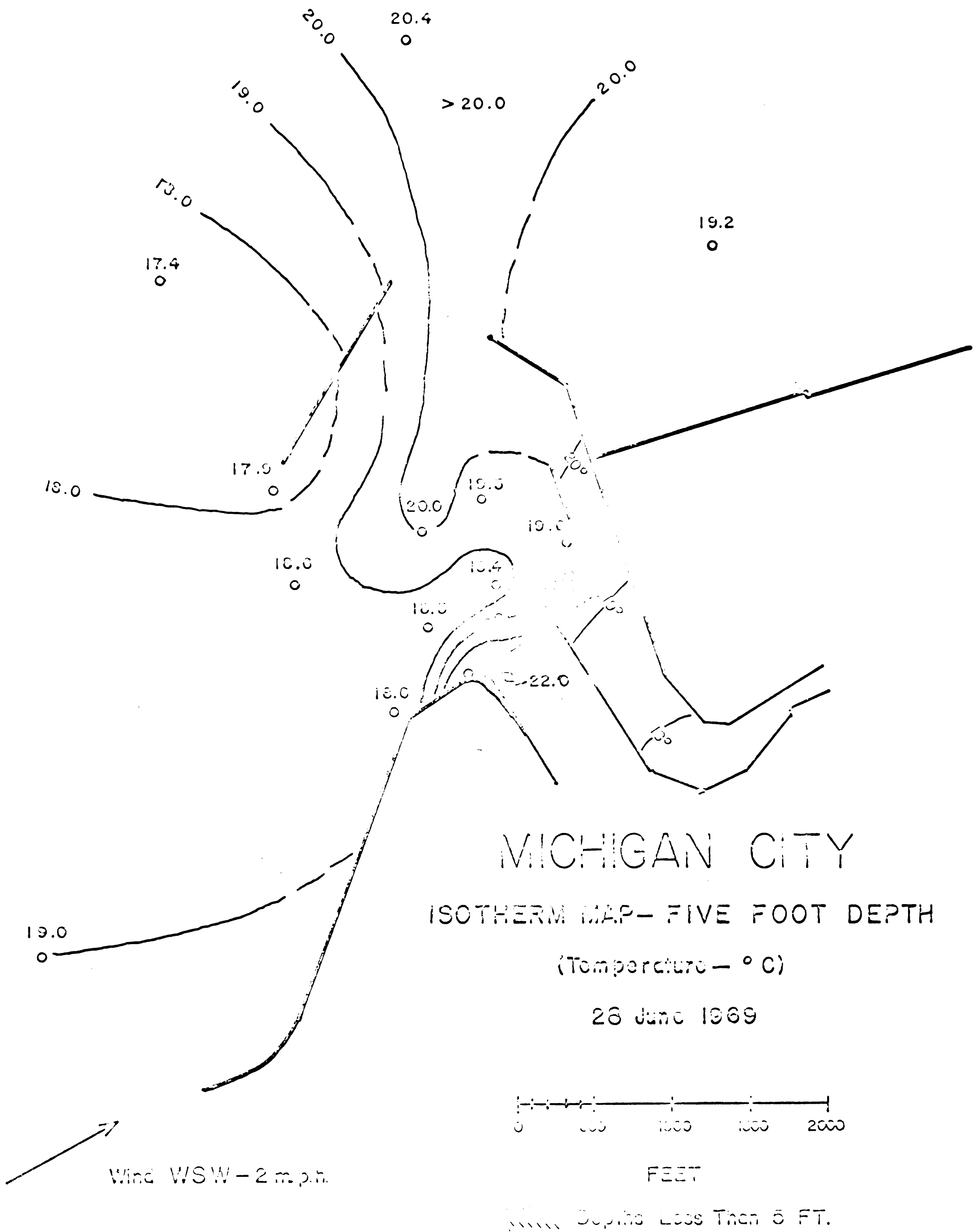
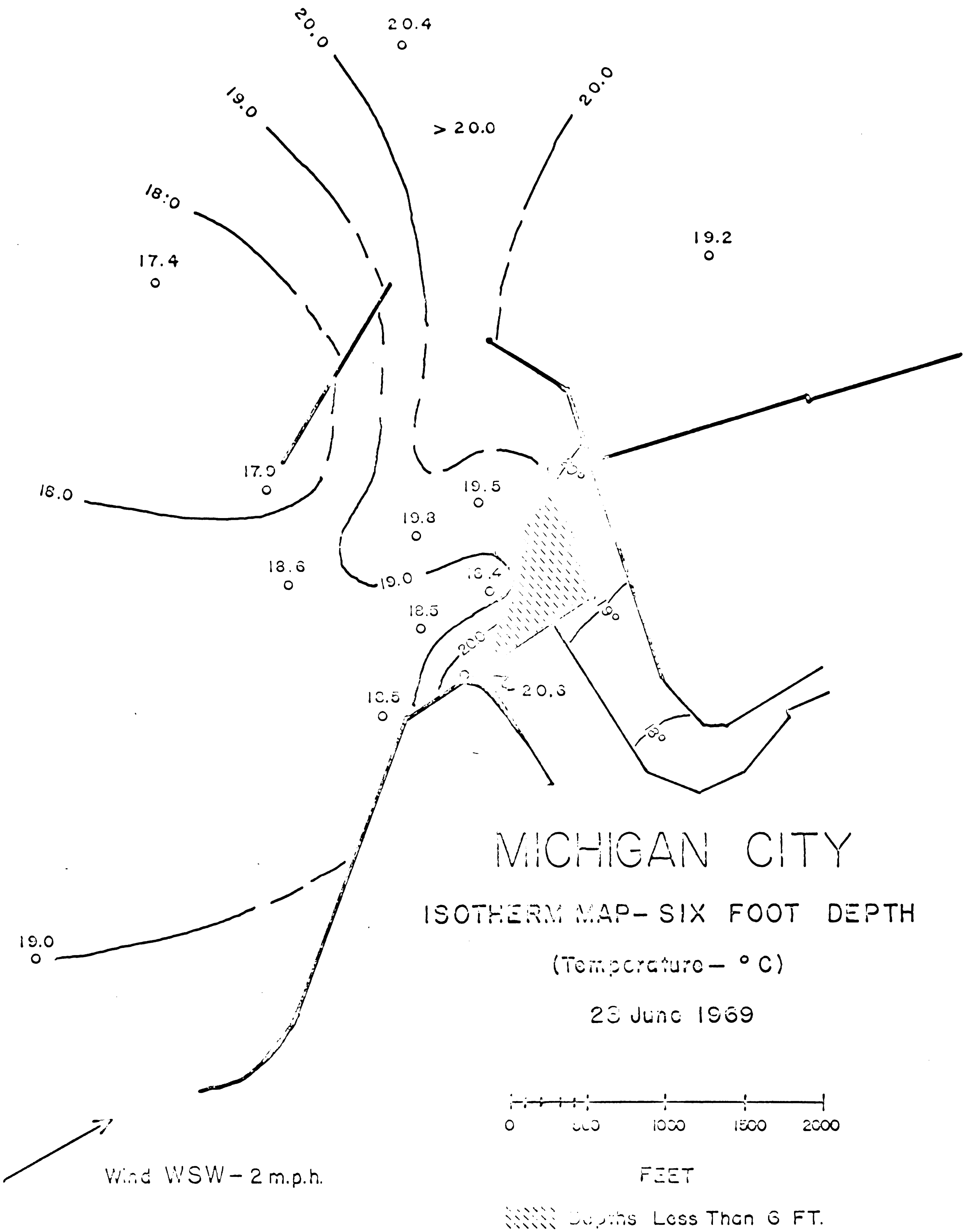
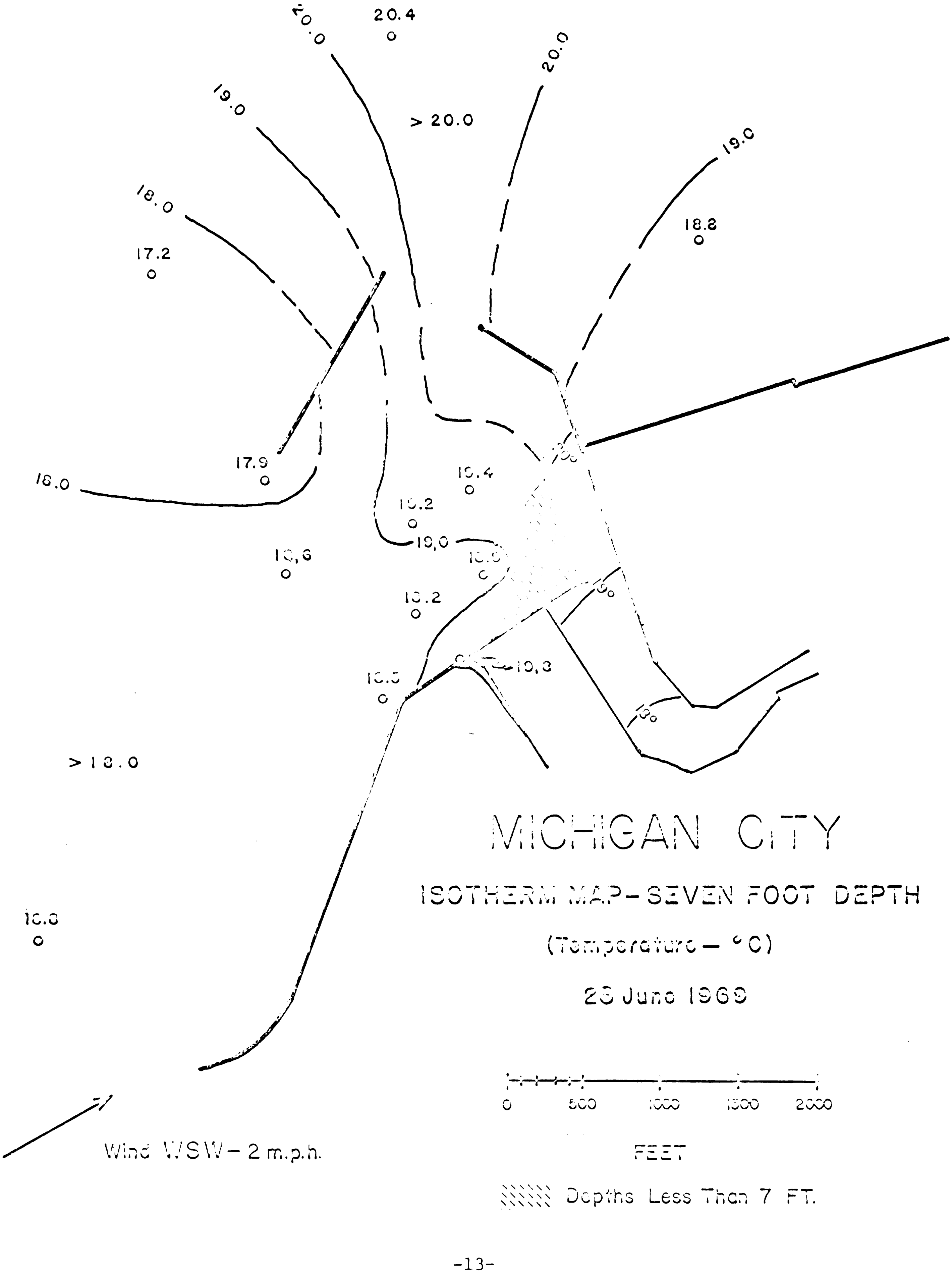

20.4
20.0
19.0
>20.0
20.0
19.2
17.4
18.0
17.9
20.0
19.0
22.0
MICHIGAN CITY
ISOTHERM MAP– FIVE FOOT DEPTH
(Temperature – °C)
26 June 1969
0
2000
FEET
Wind WSW – 2 m.p.h.
Depths Less Than 5 FT.

Figure 9



20.0
20.4
20.0
19.0
> 20.0
18.0
19.2
17.4
17.9
16.0
19.5
19.8
18.6
19.0
18.5
20.3
18.5
19.0
MICHIGAN CITY
ISOTHERM MAP- SIX FOOT DEPTH
(Temperature — °C)
23 June 1969
0
1000
1500
2000
FEET
Wind WSW - 2 m.p.h.
Less Than 6 FT.

Figure 10



20.0
20.4
20.0
19.0
> 20.0
19.0
18.0
18.8
17.2
17.9
18.0
19,0
19,3
MICHIGAN CITY
ISOTHERM MAP - SEVEN FOOT DEPTH
(Temperature — °C)
23 June 1969
0
500
1000
1500
2000
FEET
Depths Less Than 7 FT.
Wind WSW - 2 m.p.h.

Figure 11

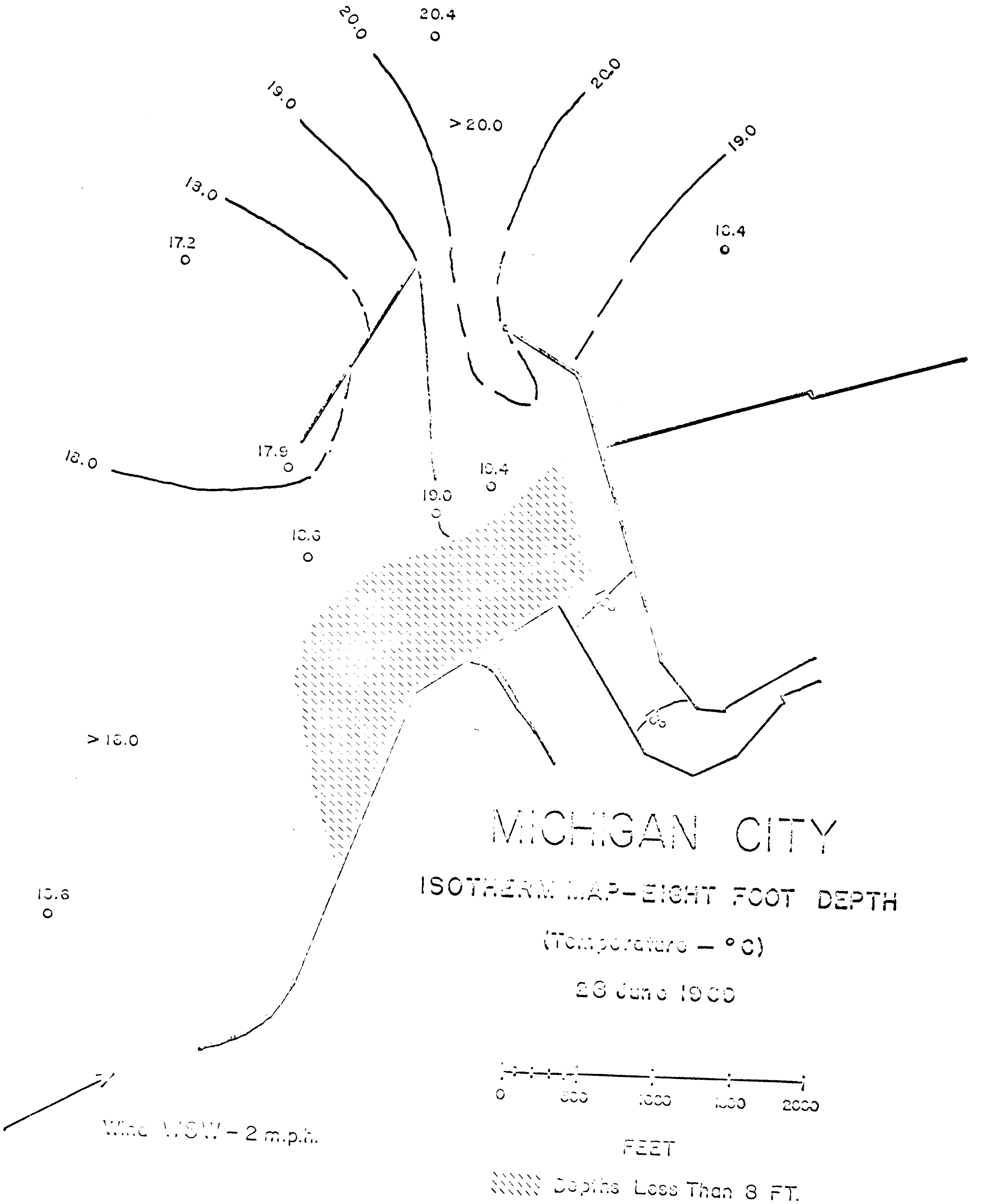

20.0
20.4
19.0
>20.0
17.2
17.9
19.0
MICHIGAN CITY
ISOTHERM MAP—EIGHT FOOT DEPTH
(Temperature — °C)
0
2000
FEET
Depths Less Than 8 FT.
Wind WSW – 2 m.p.h.

Table 1

Michigan City Power

Water Temperature Data
28 June 1969

Sta. MCP-1

Surface	-	25.2°C	77.4°F
1 ft. depth	-	25.2	77.4
2 ft. "	-	25.2	77.4
3 ft. "	-	25.2	77.4
4 ft. "	-	24.5	76.1
5 ft. "	-	22.0	71.6
6 ft. "	-	20.6	69.1
7 ft. "	-	19.8	67.6
8 ft. "	-	19.1	66.4
9 ft. "	-	19.0	66.2
10 ft. "	-	18.6	65.2
11 ft. "	-	18.2	64.8
12 ft. "	-	18.2	64.8
13 ft. "	-	18.2	64.8

Sta. MCP-2

Surface	-	20.0°C	68.0°F
1 ft. depth	-	19.4	66.9
2 ft. "	-	19.2	66.6
3 ft. "	-	18.8	65.8
4 ft. "	-	18.6	65.5
5 ft. "	-	18.6	65.5
6 ft. "	-	18.5	65.3
7 ft. "	-	18.5	65.3

Sta. MCP-3

Surface	-	23.0°C	73.4°F
1 ft. depth	-	21.4	70.5
2 ft. "	-	20.6	69.1
3 ft. "	-	19.0	66.2
4 ft. "	-	18.6	65.5
5 ft. "	-	18.5	65.3
6 ft. "	-	18.5	65.3
7 ft. "	-	18.2	64.8

Sta. MCP-4

Surface	-	22.0°C	71.6°F
1 ft. depth	-	20.9	69.8
2 ft. "	-	19.2	66.6
3 ft. "	-	19.0	66.2
4 ft. "	-	18.9	66.0
5 ft. "	-	18.9	66.0
6 ft. "	-	18.9	66.0
7 ft. "	-	18.9	66.0

Sta. MCP-5

Surface	-	21.7°C	71.1°F
1 ft. depth	-	21.0	69.8
2 ft. "		20.0	68.0

Sta. MCP-6

Surface	-	22.4°C	72.3°F
1 ft. depth	-	22.0	71.6
2 ft. "	-	21.5	70.7
3 ft. "	-	21.0	69.8
4 ft. "	-	19.8	67.6
5 ft. "	-	19.6	67.3

Sta. MCP-7

Surface	-	22.4°C	72.3°F
1 ft. depth	-	21.0	69.8
2 ft. "	-	20.6	69.1
3 ft. "	-	20.1	68.2
4 ft. "	-	19.5	67.1
5 ft. "	-	19.5	67.1
6 ft. "	-	19.5	67.1
7 ft. "	-	19.4	66.9
8 ft. "	-	19.4	66.9
9 ft. "	-	19.2	66.6
10 ft. "	-	19.2	66.6

Sta. MCP-8

Surface	-	20.2°C	68.4°F
1 ft. depth	-	20.2	68.4
2 ft. "	-	20.2	68.4
3 ft. "	-	20.2	68.4
4 ft. "	-	20.0	68.0
5 ft. "	-	20.0	68.0
6 ft. "	-	19.8	67.6
7 ft. "	-	19.2	66.6
8 ft. "	-	19.0	66.2
9 ft. "	-	18.8	65.8

Sta. MCP-9

Surface	-	19.8°C	67.6°F
1 ft. depth	-	19.0	66.2
2 ft. "	-	19.0	66.2
3 ft. "	-	18.8	65.8
4 ft. "	-	18.6	65.5
5 ft. "	-	18.6	65.5

Table 1 (Cont.)

Sta. MCP-9 (Cont.)

6 ft. depth	-	18.6°C	65.5°F
7 ft. "	-	18.6	65.5
8 ft. "	-	18.6	65.5
9 ft. "	-	18.6	65.5
10 ft. "	-	18.6	65.5
11 ft. "	-	18.6	65.5
12 ft. "	-	18.6	65.5
13 ft. "	-	18.6	65.5
14 ft. "	-	18.6	65.5
15 ft. "	-	18.6	65.5
16 ft. "	-	18.2	64.8
17 ft. "	-	18.2	64.8

Sta. MCP-10

Surface	-	21.0°C	69.8°F
1 ft. depth	-	20.1	68.2
2 ft. "	-	19.8	67.6
3 ft. "	-	19.2	66.6
4 ft. "	-	19.0	66.2
5 ft. "	-	19.0	66.2
6 ft. "	-	19.0	66.2
7 ft. "	-	18.8	65.8
8 ft. "	-	18.6	65.5
9 ft. "	-	18.2	64.8
10 ft. "	-	18.1	64.6
11 ft. "	-	18.0	64.4
12 ft. "	-	18.0	64.4
13 ft. "	-	18.0	64.4
14 ft. "	-	18.0	64.4
15 ft. "	-	18.0	64.4
16 ft. "	-	18.0	64.4
17 ft. "	-	18.0	64.4
18 ft. "	-	18.0	64.4
19 ft. "	-	18.0	64.4
20 ft. "	-	18.0	64.4
21 ft. "	-	18.0	64.4

Sta. MCP-11

Surface	-	20.0°C	68.0°F
1 ft. depth	-	18.5	65.3
2 ft. "	-	18.4	65.1
3 ft. "	-	18.0	64.4
4 ft. "	-	17.9	64.2
5 ft. "	-	17.9	64.2
6 ft. "	-	17.9	64.2
7 ft. "	-	17.9	64.2
8 ft. "	-	17.9	64.2
9 ft. "	-	17.9	64.2
10 ft. "	-	17.8	64.0
11 ft. "	-	17.8	64.0
12 ft. "	-	17.8	64.0

Sta. MCP-11 (Cont.)

13 ft. depth	-	17.8°C	64.0°F
14 ft. "	-	17.8	64.0
15 ft. "	-	17.8	64.0
16 ft. "	-	17.8	64.0
17 ft. "	-	17.8	64.0
18 ft. "	-	17.8	64.0
19 ft. "	-	17.8	64.0
20 ft. "	-	17.8	64.0

Sta. MCP-12

Surface	-	21.0°C	69.8°F
1 ft. depth	-	19.8	67.6
2 ft. "	-	19.0	66.2
3 ft. "	-	18.0	64.4
4 ft. "	-	17.4	63.3
5 ft. "	-	17.4	63.3
6 ft. "	-	17.4	63.3
7 ft. "	-	17.2	63.0
8 ft. "	-	17.2	63.0
9 ft. "	-	17.2	63.0
10 ft. "	-	17.0	62.6
11 ft. "	-	17.0	62.6
12 ft. "	-	17.0	62.6
13 ft. "	-	17.0	62.6
14 ft. "	-	17.0	62.6
15 ft. "	-	17.0	62.6
16 ft. "	-	17.0	62.6
17 ft. "	-	16.8	62.2
18 ft. "	-	16.8	62.2
19 ft. "	-	16.8	62.2
20 ft. "	-	16.8	62.2
21 ft. "	-	16.8	62.2
22 ft. "	-	16.8	62.2
23 ft. "	-	16.8	62.2
24 ft. "	-	16.8	62.2
25 ft. "	-	16.8	62.2
26 ft. "	-	16.8	62.2
27 ft. "	-	16.8	62.2
28 ft. "	-	16.8	62.2
29 ft. "	-	16.8	62.2
30 ft. "	-	16.8	62.2
31 ft. "	-	16.8	62.2
32 ft. "	-	16.8	62.2
33 ft. "	-	16.8	62.2
34 ft. "	-	16.8	62.2
35 ft. "	-	16.8	62.2
36 ft. "	-	16.8	62.2
37 ft. "	-	16.8	62.2
38 ft. "	-	16.8	62.2
39 ft. "	-	16.8	62.2
40 ft. "	-	16.8	62.2

Table 1 (Cont.)

Sta. MCP-13

Surface	-	21.5°C	70.7°F
1 ft. depth	-	21.5	70.7
2 ft. "	-	21.0	69.8
3 ft. "	-	20.6	69.1
4 ft. "	-	20.5	68.9
5 ft. "	-	20.4	68.7
6 ft. "	-	20.4	68.7
7 ft. "	-	20.4	68.7
8 ft. "	-	20.4	68.7
9 ft. "	-	20.2	68.4
10 ft. "	-	19.9	67.8
11 ft. "	-	19.9	67.8
12 ft. "	-	19.8	67.6
13 ft. "	-	19.5	67.1
14 ft. "	-	19.0	66.2
15 ft. "	-	18.0	64.4
16 ft. "	-	17.9	64.2
17 ft. "	-	17.8	64.0
18 ft. "	-	17.8	64.0
19 ft. "	-	17.8	64.0
20 ft. "	-	17.5	64.0
21 ft. "	-	17.5	64.0
22 ft. "	-	17.4	63.3
23 ft. "	-	17.4	63.3
24 ft. "	-	17.4	63.3
25 ft. "	-	17.4	63.3
26 ft. "	-	17.2	63.0
27 ft. "	-	17.0	62.6
28 ft. "	-	17.0	62.6
29 ft. "	-	17.0	62.6
30 ft. "	-	17.0	62.6
31 ft. "	-	17.0	62.6
32 ft. "	-	17.0	62.6
33 ft. "	-	17.0	62.6
34 ft. "	-	17.0	62.6
35 ft. "	-	17.0	62.6
36 ft. "	-	17.0	62.6
37 ft. "	-	17.0	62.6
38 ft. "	-	17.0	62.6
39 ft. "	-	17.0	62.6
40 ft. "	-	17.0	62.6
41 ft. "	-	17.0	62.6
42 ft. "	-	17.0	62.6
43 ft. "	-	17.0	62.6
44 ft. "	-	17.0	62.6
45 ft. "	-	17.0	62.6
46 ft. "	-	17.0	62.6
47 ft. "	-	17.0	62.6

Sta. MCP-14

Surface	-	21.0°C	69.8°F
1 ft. depth	-	20.5	68.9
2 ft. "	-	20.0	68.0
3 ft. "	-	19.8	67.6
4 ft. "	-	19.2	66.6
5 ft. "	-	19.2	66.6
6 ft. "	-	19.2	66.6
7 ft. "	-	18.8	65.8
8 ft. "	-	18.4	65.1
9 ft. "	-	18.2	64.8
10 ft. "	-	18.0	64.4
11 ft. "	-	18.0	64.4
12 ft. "	-	18.0	64.4
13 ft. "	-	18.0	64.4
14 ft. "	-	18.0	64.4
15 ft. "	-	18.0	64.4
16 ft. "	-	17.4	63.3

Sta. MCP-15

Surface	-	21.6°C	70.9°F

Sta. MCP-16

Surface	-	18.0°C	64.4°F
1 ft. depth	-	18.0	64.4
2 ft. "	-	18.0	64.4
3 ft. "	-	18.0	64.4
4 ft. "	-	18.0	64.4
5 ft. "	-	18.0	64.4
6 ft. "	-	18.0	64.4
7 ft. "	-	18.0	64.4
8 ft. "	-	18.0	64.4
9 ft. "	-	18.0	64.4
10 ft. "	-	18.0	64.4
11 ft. "	-	18.0	64.4
12 ft. "	-	18.0	64.4
13 ft. "	-	18.0	64.4
14 ft. "	-	18.0	64.4
15 ft. "	-	18.0	64.4
16 ft. "	-	18.0	64.4
17 ft. "	-	18.0	64.4
18 ft. "	-	18.0	64.4

Zooplankton: Station MCP-16 in the intake, MCP-1 in the outfall mouth, Station MCP-3 in the plume axis, Station MCP-8, and Station MCP-13 at the far outer end of the plume as determined by surface temperature.

Benthos: Stations MCP-1 through MCP-14 (MCP-15 being an air temperature station only). Our check-list system broke down, and benthos samples in the river at the plant intake were not obtained. While this omission was undesirable, it is not so bad as it appears for the polluted river environment would not be comparable to the much cleaner lake and harbor environments.

The biological data are presented in Tables 2 through 7. Phytoplankton and zooplankton are presented in terms of organisms per liter of water, while benthos are given in numbers per square meter of bottom surface.

Discussion of Biological Data

The phytoplankton collections (Tables 2 through 5) indicate that a total of 1,952,000 cells per liter were present at the intake and could be presumed to be passed through the plant's condensers. Some kill-off of phytoplankters during passage through the plant is indicated by the fact that phytoplankton numbers in the mouth of the outfall channel (Station MCP-1) were 1,671,000 cells per liter. Increase in cells per liter was observed at Stations MCP-3 in the plume axis and at Station MCP-8 at the edge of the plume. Numbers at these stations were, respectively, 4,092,000 and 2,235,000 cells per liter and included increases in some of the normal southern Lake Michigan species of diatoms but also increases in the numbers of the troublesome blue-green algae listed as "Oscillatoria species (spp.)" and the yellow-brown alga "Dinobryon spp." At present we cannot tell whether these increases were due to plant heat or to foreign water masses drifting in from the southwest.

Table 2

Phytoplankton

Station MCP-16, at intake, Michigan City
28 June 1969

Organism	No. of Colonies	Cells per Liter
Synedra spp.	---	77,818
Tabellaria fenestrata	29,848	198,276
Melosira spp.	53,300	414,674
Diatoma tenue	6,396	33,046
Fragilaria capucina	1,066	31,980
Fragilaria crotonensis	5,330	74,620
Nitzschia spp.	---	3,198
Dinobryon spp.	20,254	923,156
Oscillatoria spp.	---	132,184
Cyclotella spp.	---	40,508
Rhizosolenia spp.	---	6,396
Asterionella formosa	---	6,396
Gyrosigma sp.	---	1,066
Amphiprora spp.	---	9,594
		1,952,000

Table 3

Phytoplankton

Station MCP-1, at outfall, Michigan City
28 June 1969

Organism	No. of Colonies	Cells per Liter
Tabellaria fenestrata	77,680	644,424
Synedra spp.	---	49,144
Cyclotella spp.	---	13,475
Melosira spp.	4,756	35,669
Fragilaria crotonensis	8,719	152,189
Fragilaria capucina	7,134	206,882
Nitzschia sp.	---	2,378
Diatoma tenue	3,171	12,682
Oscillatoria spp.	---	62,619
Dinobryon spp.	15,853	489,858
Ankistrodesmus sp.	---	1,585
Scenedesmus	---	793
		1,671,000

Table 4

Phytoplankton

Station MCP-3, in the plume, Michigan City
28 June 1969

Organism	No. of Colonies	Cells per Liter
Tabellaria fenestrata	144,715	1,254,665
Synedra spp.	---	99,755
Diatoma tenue	18,265	82,895
Cyclotella spp.	---	9,835
Melosira spp.	4,215	32,315
Nitzschia spp.	---	9,835
Fragilaria crotonensis	19,670	626,630
Fragilaria capucina	18,265	490,345
Dinobryon spp.	18,265	1,115,570
Oscillatoria spp.	---	369,515
Navicula sp.	---	1,405
		4,092,000

Table 5

Phytoplankton

Station MCP-8, at edge of plume, Michigan City
28 June 1969

Organism	No. of Colonies	Cells per Liter
Tabellaria fenestrata	66,240	557,888
Synedra spp.	---	83,904
Diatoma tenue v. elongatum	19,136	66,240
Fragilaria capucina	5,888	262,016
Fragilaria crotonensis	19,136	418,048
Melosira spp.	5,888	54,464
Oscillatoria spp.	---	294,400
Cyclotella spp.	---	16,192
Nitzschia spp.	---	1,472
Rhizosolenia spp.	---	4,416
Dinobryon spp.	4,416	476,928
		2,235,000

Table 6

POWER PLANT SURVEYS - PRIMARY ZOOPLANKTON COUNTS

Michigan City, Lake Michigan (No. Org./Liter)

	MCP-1 Outfall 6/28/69	MCP-3 6/28/69	MCP-8 6/28/69	MCP-13 6/28/69	MCP-16 Intake 6/28/69
CALANOID COPEPODS:					
Diaptomus sp.	0.10	0.06	0.15	0.76	0.30
Epischura lacustris					
Others					
CYCLOPOID COPEPODS	0.95	0.12		0.24	0.27
ROTIFERS:					
Asplanchna sp.	5.63	42.37	1.17	0.68	21.82
(Other spp. are too small for this net)					
CLADOCERA:					
Daphnia retrocurva	0.05				
Other Daphnia				0.01	
Bosmina sp.	1.20	0.06	0.29	5.21	0.47
Chydorus sphaericus	0.05				
Ceriodaphnia reticulata					
Leptodora kindtii					
Sida crystallina					0.03
OTHER GROUPS:	1 Mite				
REMARKS:	Many dead or broken				

Table 7

Benthos, numbers per meter^2

Michigan City Generating Station
28 June 1969

Station	Amphipods	Oligochaetes	Sphaeriidae	Tendipedidae	Others
MCP-1	0	0	0	8	0
MCP-2	0	0	0	0	0
MCP-3	0	0	0	43	0
MCP-4	0	0	0	0	0
MCP-5	0	0	0	0	0
MCP-6	0	0	0	0	0
MCP-7	17	0	0	8	0
MCP-8	17	0	0	0	0
MCP-9	243	17	0	321	17 Daphnia
MCP-10	8	17	0	8	0
MCP-11	86	17	0	182	0
MCP-12	1878	1112	243	243	0
MCP-13	1599	2147	330	199	0
MCP-14	139	104	0	773	0

In the zooplankton data there was a decrease in total numbers between intake and outfall (22.89 organisms per liter to 7.98), and many dead or broken organisms were observed in the outfall sample (see Table 6). Beyond the outfall channel mouth there is a rise of total organisms per liter to 42.61 but this increase is due solely to the rotifer, Asplanchna sp. At Station MCP-8 at the edge of the plume the population was composed of three organism groups all of which were in lower numbers than in the intake, with a total population of 1.61 organisms per liter. Perhaps more significant is the condition at Station MCP-13 at the far end of the demonstrable plume where, with population composition differing only slightly from the intake, the total numbers of organisms per liter was down to 6.90 with only the cladoceran, Bosmina sp., and the copepod, Diaptomus sp., showing any rise above intake levels. As in the phytoplankton, we are unsure whether drifting in of other water masses affected the results.

The benthos data are presented in Table 7. In the analysis of these data particular attention has been paid to the number of clean-water-loving amphipods and to the number of pollution tolerant oligochaetes. In the shallow stations, MCP-1 through MCP-8, no amphipods or oligochaetes were collected. These stations are subject to both wave action, refracted around the outer breakwall, and the scouring action of the plant's cooling water discharge. At Stations MCP-13 and 14, where both the heated plant plume and the organic contribution from the river outflow might be expected to be most consistently present under the prevailing southwest winds, there were abundant amphipods and modest numbers of oligochaetes (as oligochaetes numbers go). It should be pointed out here that Stations MCP-12, 13, and 14 were the only stations in the survey area where the bottom was of the silty fine sand that in Lake Michigan is typified by abundant benthic organisms. Except for Station MCP-10 which was on hard grey clay, every other station in the area was bottomed by clean (not silty) sand. The higher benthic populations at Stations 12, 13, and 14 are much more apt to be explained by the presence of silt, with its concommitant detrital food materials in the sand than by any influence of the plant's thermal plume.

So far as benthos indicate, it appears that wave action and current scour from the plant's discharge of condenser cooling water are dominant features over a limited shallow-water portion of the harbor, but beyond this local area the benthos do not appear to sense the presence of the plant's cooling water.

In summary, on 28 June 1969 the waste heat from the Michigan City Generating Station did not appear to affect the benthic organisms. The plankton results may have been influenced by water masses drifting in from the southwest.

Waukegan, Illinois, Light Wind

On 30 June 1969 the R/V MYSIS conducted a survey of the thermal plume from the Waukegan Generating Station. The wind was from the west-southwest at 2 mph, but south winds of 18 mph had blown during the preceding afternoon and evening and the plume was moving northward along the shore under the residual current from the preceding south wind.

The plume could be traced to a point two miles north of the outfall. Lakeward its greatest extent was about 3000 feet, with the last third of this length being only about 1000 feet wide.

Intake temperature was 12.8° and outfall temperature was 16.6; these are, respectively, the surface temperature outside a fish net strung across the intake, and the surface temperature at the point where the MYSIS went aground in 7 feet of water as she moved up the outflow channel.

A surface thermistor trailing from the ship's bowsprit was used to determine whether we were in or out of the plume. All station data were taken with an additional thermistor chain spaced at one-foot intervals. Navigation was by radar ranges and bearings.

Station locations are indicated in Figure 12.

Surface temperature distribution is shown in Figure 13. Surface water warmer than 16°C occupied a limited area north of the plant's breakwall. The vast majority of the plume's surface area was occupied by water of 13° to 15°, and water of 13° to 14° occupied more than half the plume area. The 13° isotherm is here taken as the edge of the plume, inferring retention of 0.2° of plant-added heat. Figures 14 through 22 show the subsurface temperature distribution from a depth of 1 foot to 9 feet. Table 8 lists the surface and subsurface temperatures for all stations at a 1-foot interval to each station's maximum depth. The upwind stations, WP-2 and 3, agree in indicating a common bottom temperature of 12.6° but disagree in indicating surface temperatures of 12.8° and 13.0°. We have elected to honor 12.8° as the most probable incoming ambient temperature; note, from Table 8, that Station WP-4 is isothermal at this temperature throughout 18 feet of depth. We assign 12.9° to being within the limits of error of this experiment and do not consider it to be contourable as being a part of the plant's thermal plume. We have doubts, unsupported by evidence, that 13.0° should be accepted as the edge of the plant's thermal plume, but accepting it as such gives an ultraconservative large extent to the plume.

Under these conditions the plume could be identified, at nine feet of depth, as extending about 6000 feet northward along the shore and reaching about 3000 feet off shore. Too many stations drop out as depth increases to allow reasonable contouring at the greater depths.

Samples of phytoplankton, zooplankton, and benthos were taken at Stations WP-1 in the outfall channel, WP-2 as near the intake channel as possible, and at Station WP-13 near the outfall channel and in the thermal plume of the plant.

Discussion of Biological Data

Phytoplankton were abundant at Waukegan. Kill-off by passage through the plant was shown by a drop in numbers from 6,632,000 cells per liter in the intake

Figure 12

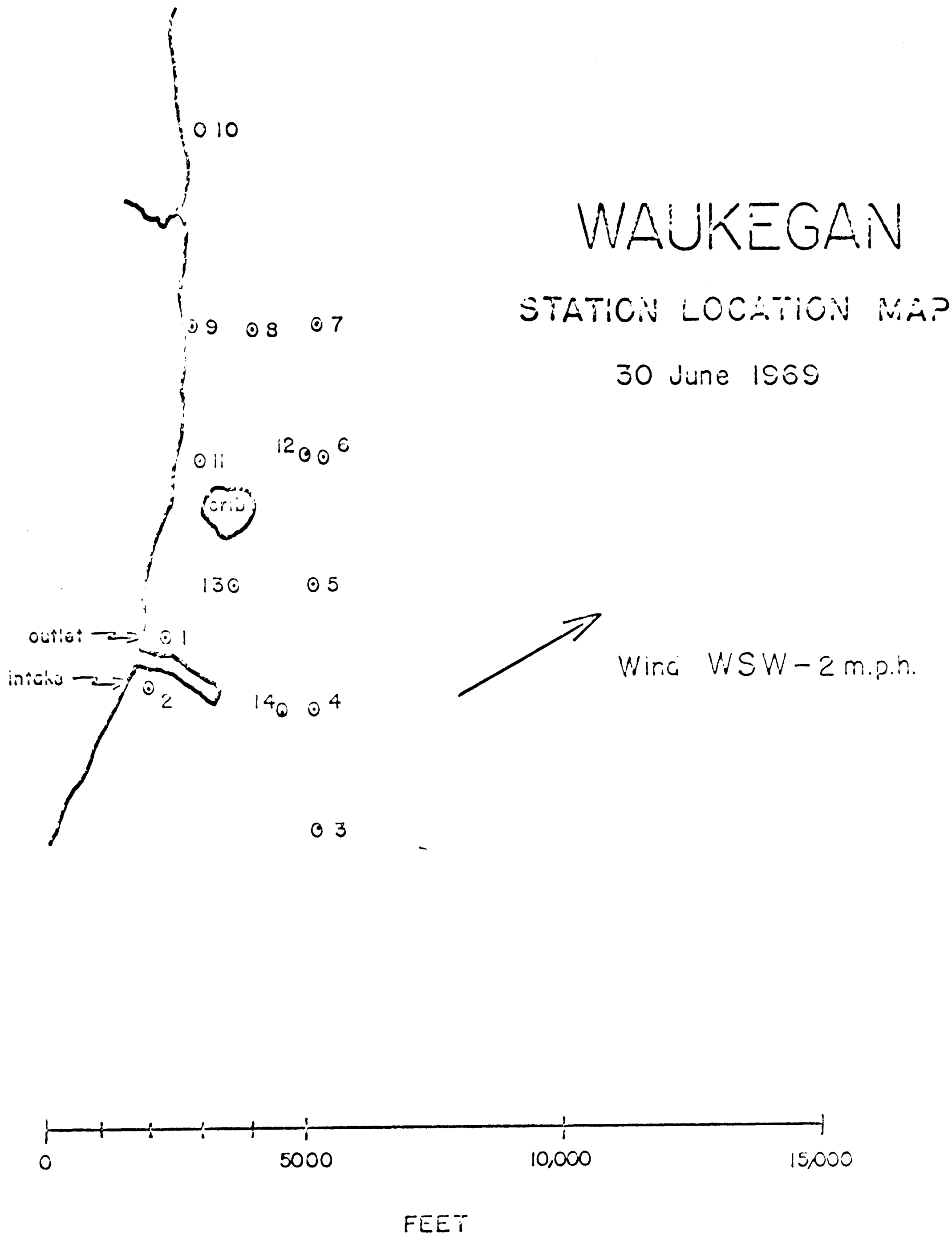

WAUKEGAN
STATION LOCATION MAP
30 June 1969
10
9
8
7
11
12
6
crib
13
5
outlet
1
intake
2
14
4
3
Wind WSW - 2 m.p.h.
0
5000
10,000
15,000
FEET

Figure 13

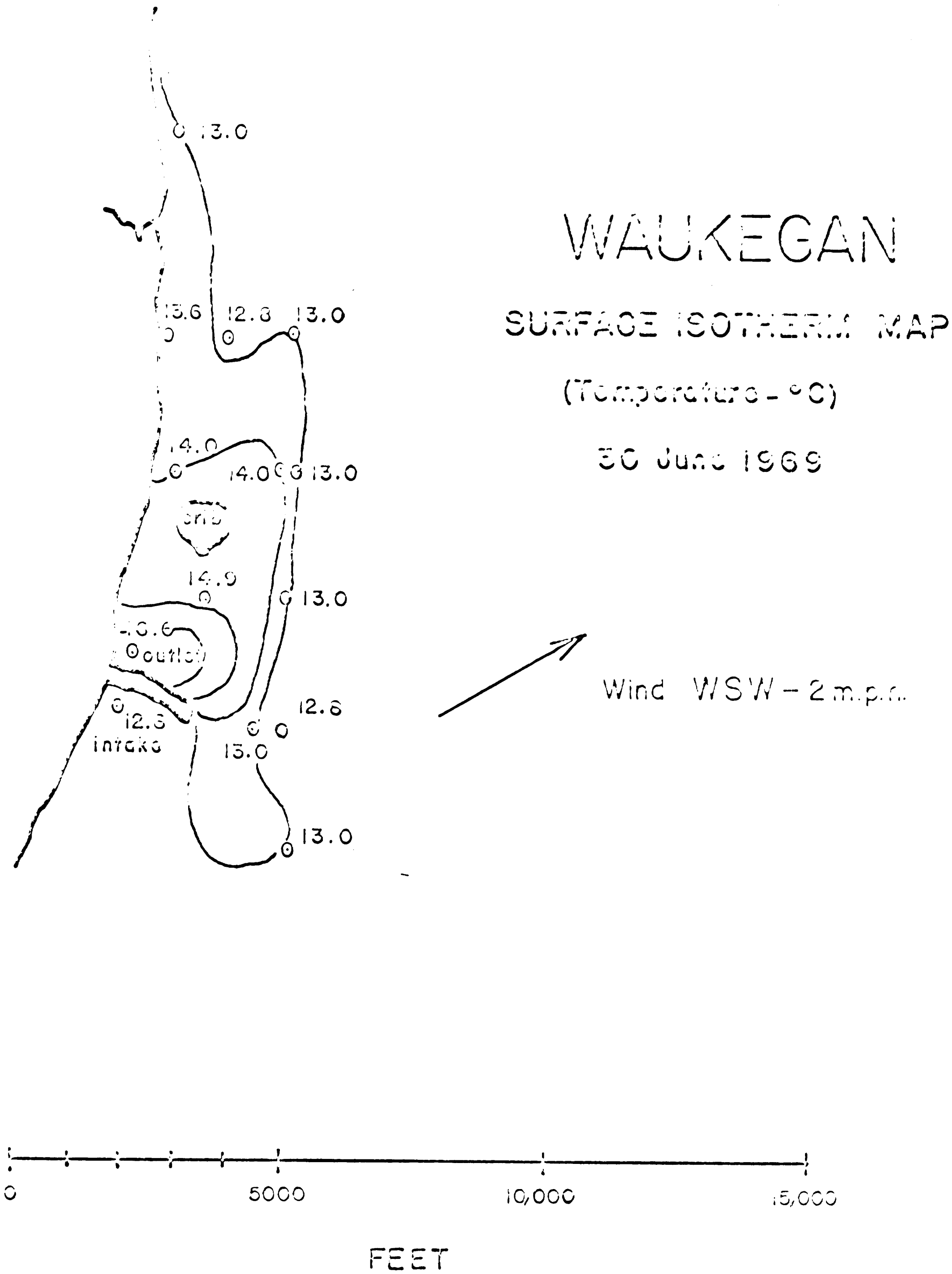

WAUKEGAN
SURFACE ISOTHERM MAP
(Temperature - °C)
30 June 1969
Wind WSW - 2 m.p.h.
13.0
12.8
14.0
14.9
outlet
intake
0
5000
10,000
15,000
FEET

Figure 14

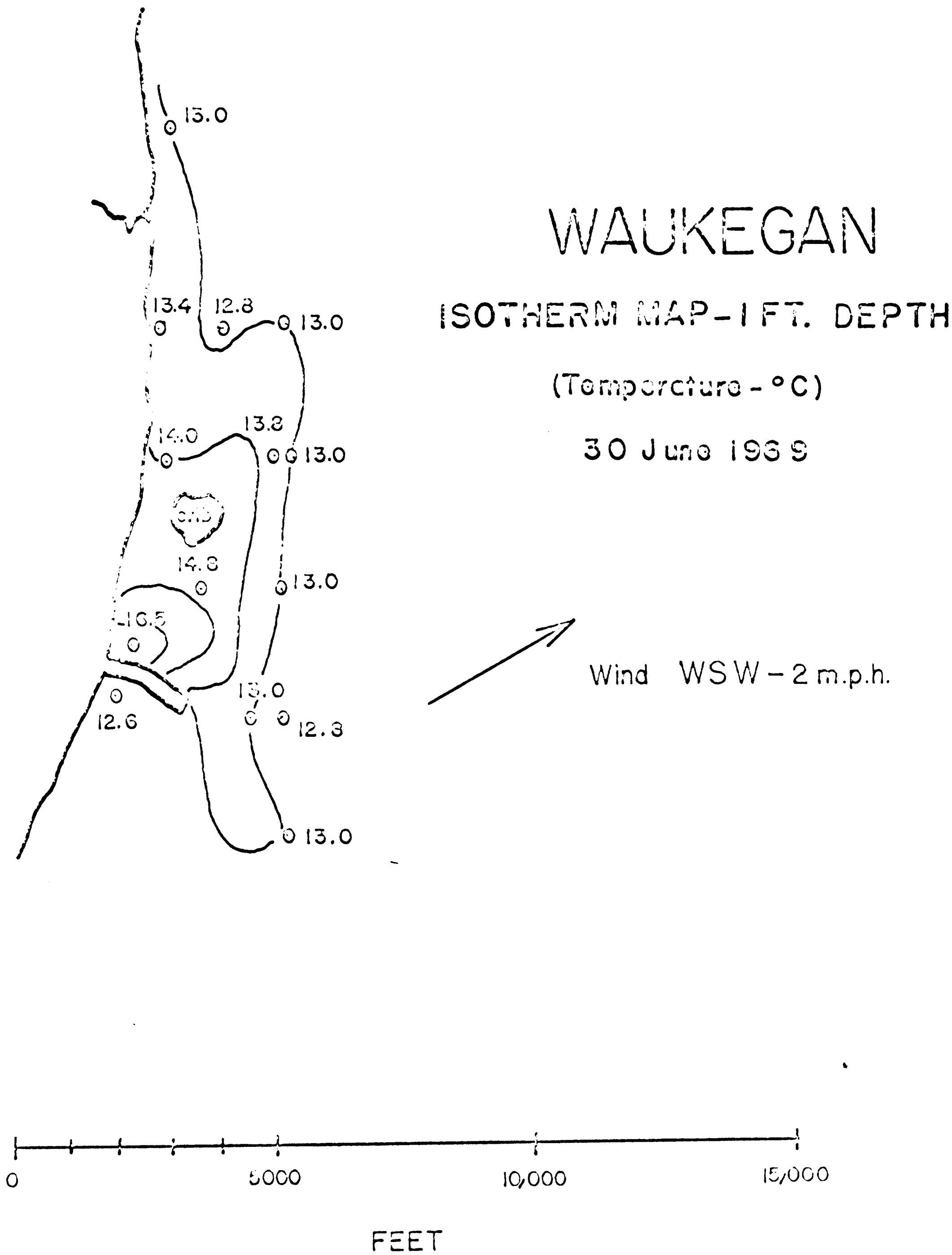

WAUKEGAN
ISOTHERM MAP-1 FT. DEPTH
(Temperature - °C)
30 June 1969
13.0
13.4
12.8
13.0
14.0
13.8
13.0
14.8
13.0
16.5
13.0
12.6
12.3
13.0
Wind WSW - 2 m.p.h.
0
5000
10,000
15,000
FEET

Figure 15

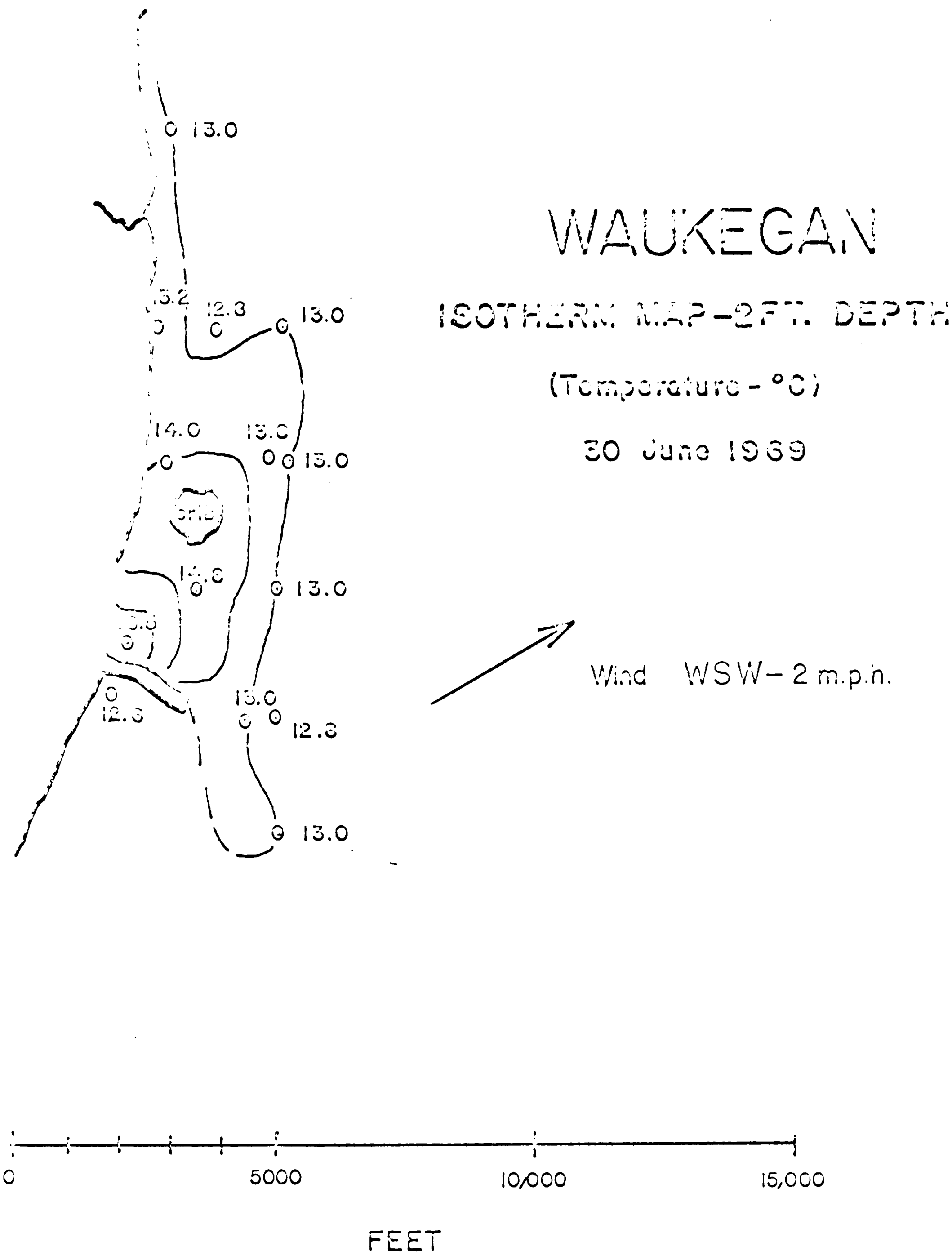

WAUKEGAN
ISOTHERM MAP-2FT. DEPTH
(Temperature - °C)
30 June 1969
Wind WSW-2 m.p.h.
13.0
12.8
13.0
14.0
13.0
13.0
14.8
13.0
12.8
13.0
12.8
13.0
0
5000
10,000
15,000
FEET

Figure 16

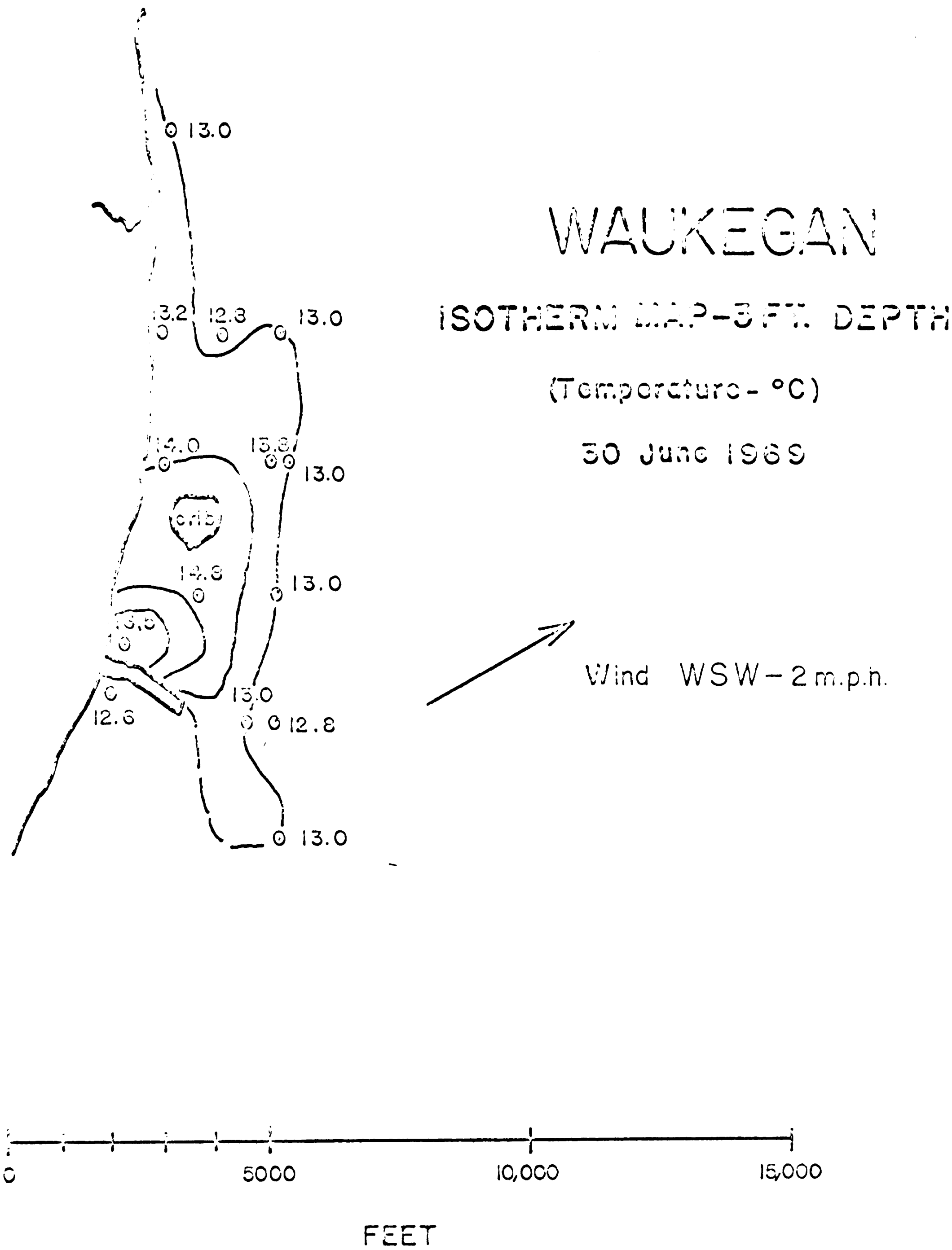
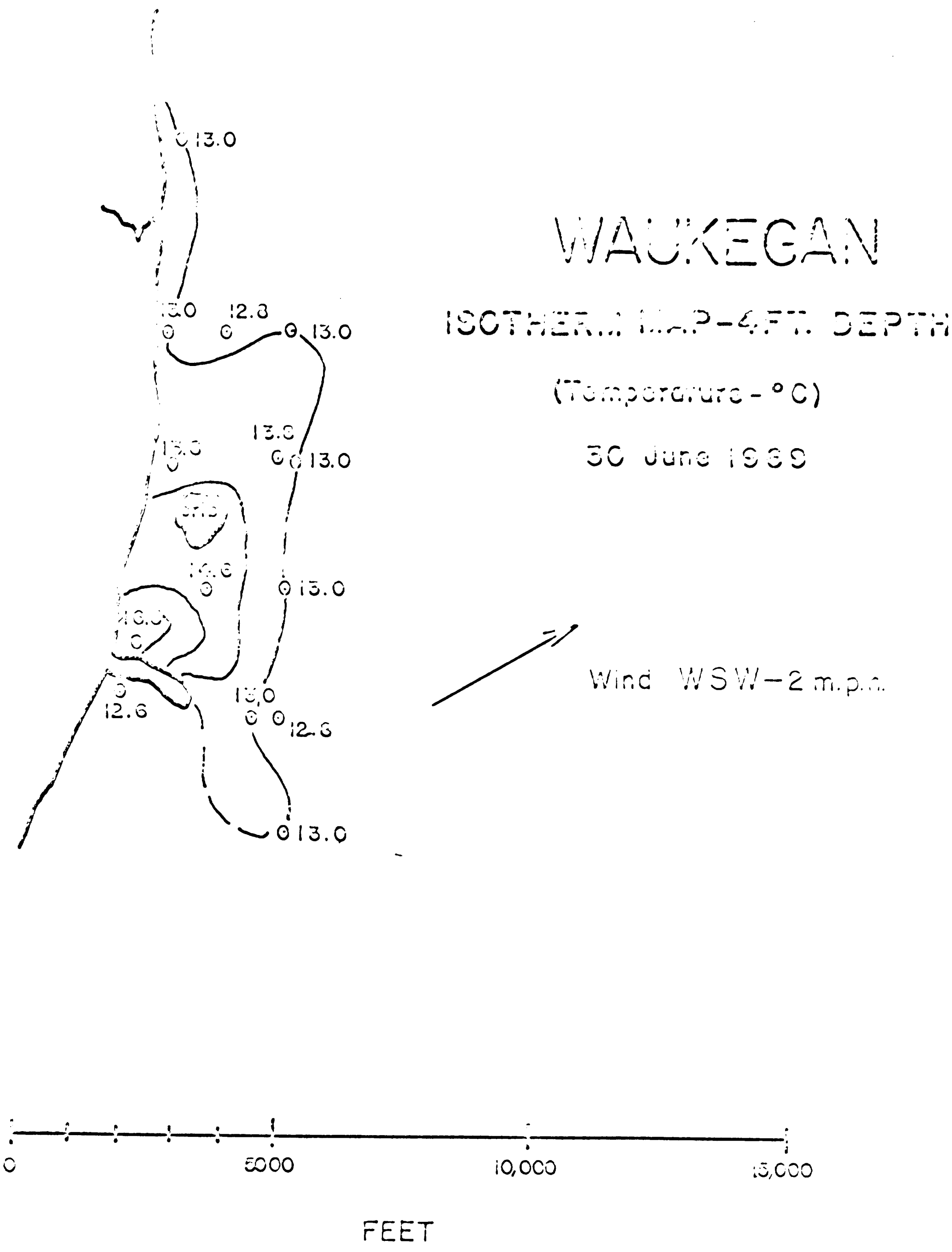

WAUKEGAN
ISOTHERM MAP-3 FT. DEPTH
(Temperature - °C)
30 June 1969
Wind WSW-2 m.p.h.
13.0
12.8
13.0
14.0
13.0
crib
14.8
13.0
12.6
13.0
12.8
13.0
0
5000
10,000
15,000
FEET

Figure 17



WAUKEGAN
13.0
12.8
13.0
14.6
15.0
12.6
Wind WSW-2 m.p.h.
0
5000
10,000
FEET

Figure 18

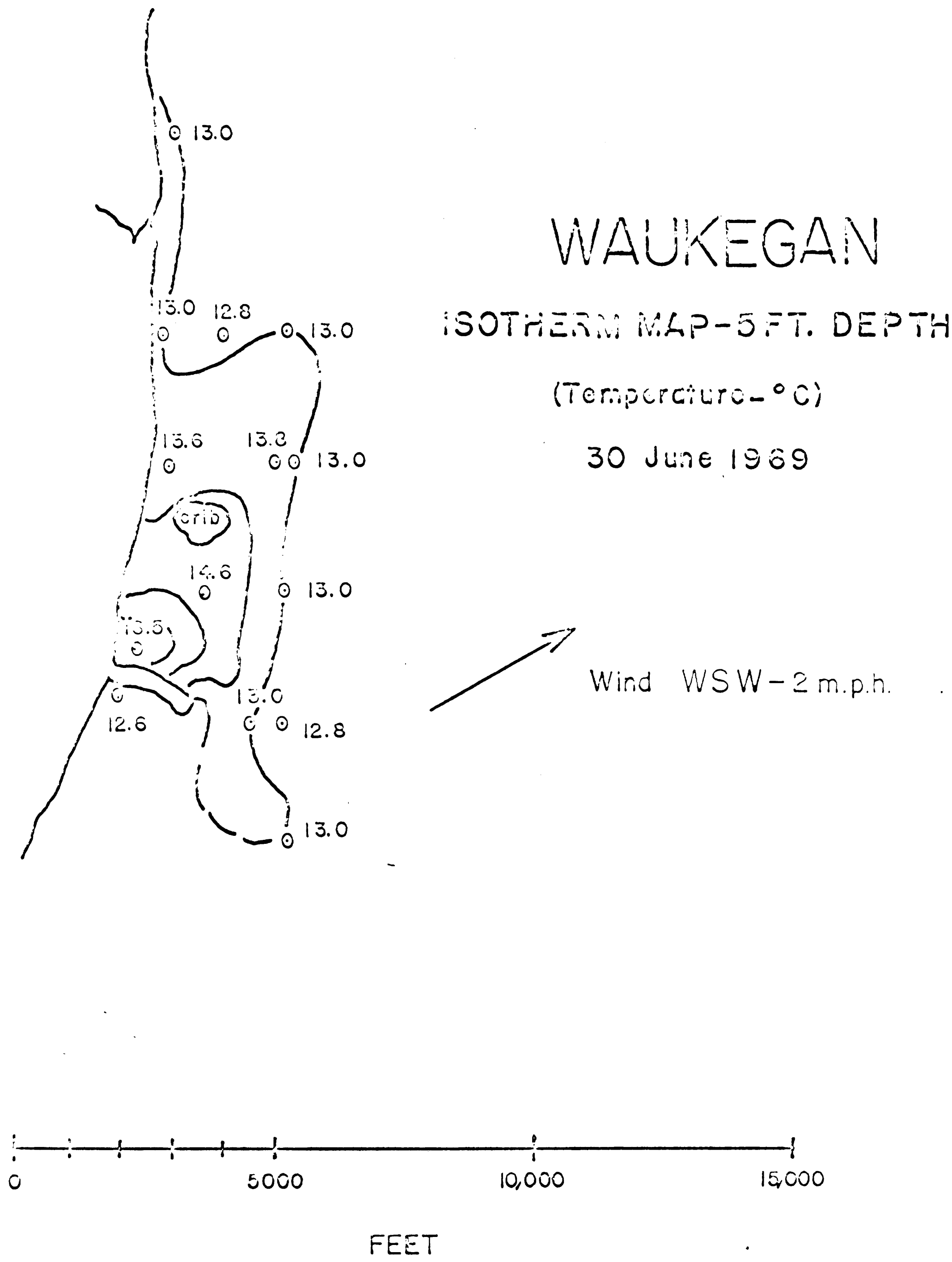
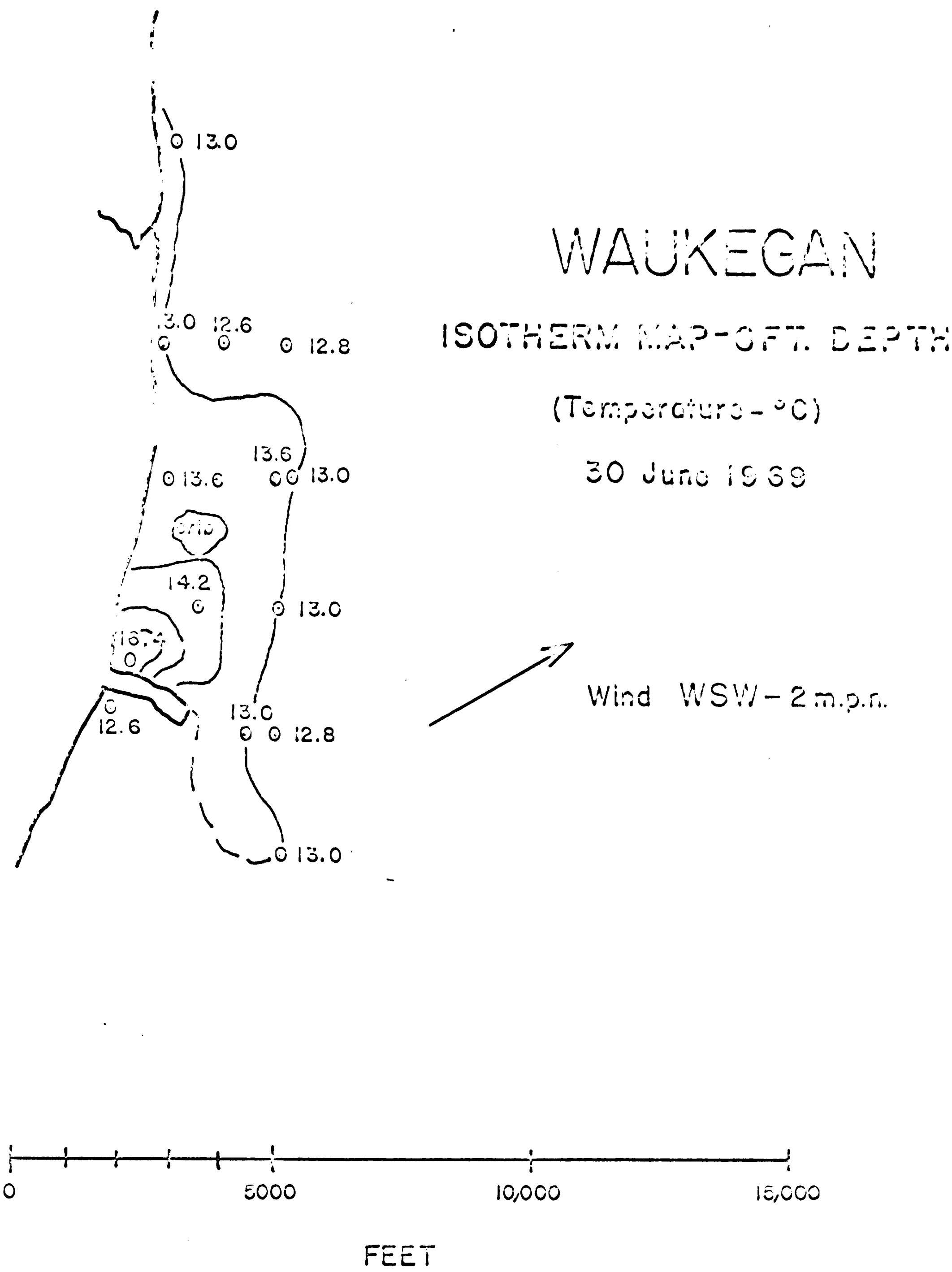

13.0
13.0
12.8
13.0
13.6
13.8
13.0
crib
14.6
13.0
13.5
12.6
13.0
12.8
13.0
WAUKEGAN
ISOTHERM MAP-5 FT. DEPTH
(Temperature-°C)
30 June 1969
Wind WSW-2 m.p.h.
0
5000
10,000
15,000
FEET

Figure 19



WAUKEGAN
ISOTHERM MAP-0FT. DEPTH
(Temperature - °C)
30 June 1969
Wind WSW - 2 m.p.h.
13.0
12.6
12.8
13.6
14.2
12.6
13.0
0
5000
10,000
15,000
FEET

Figure 20

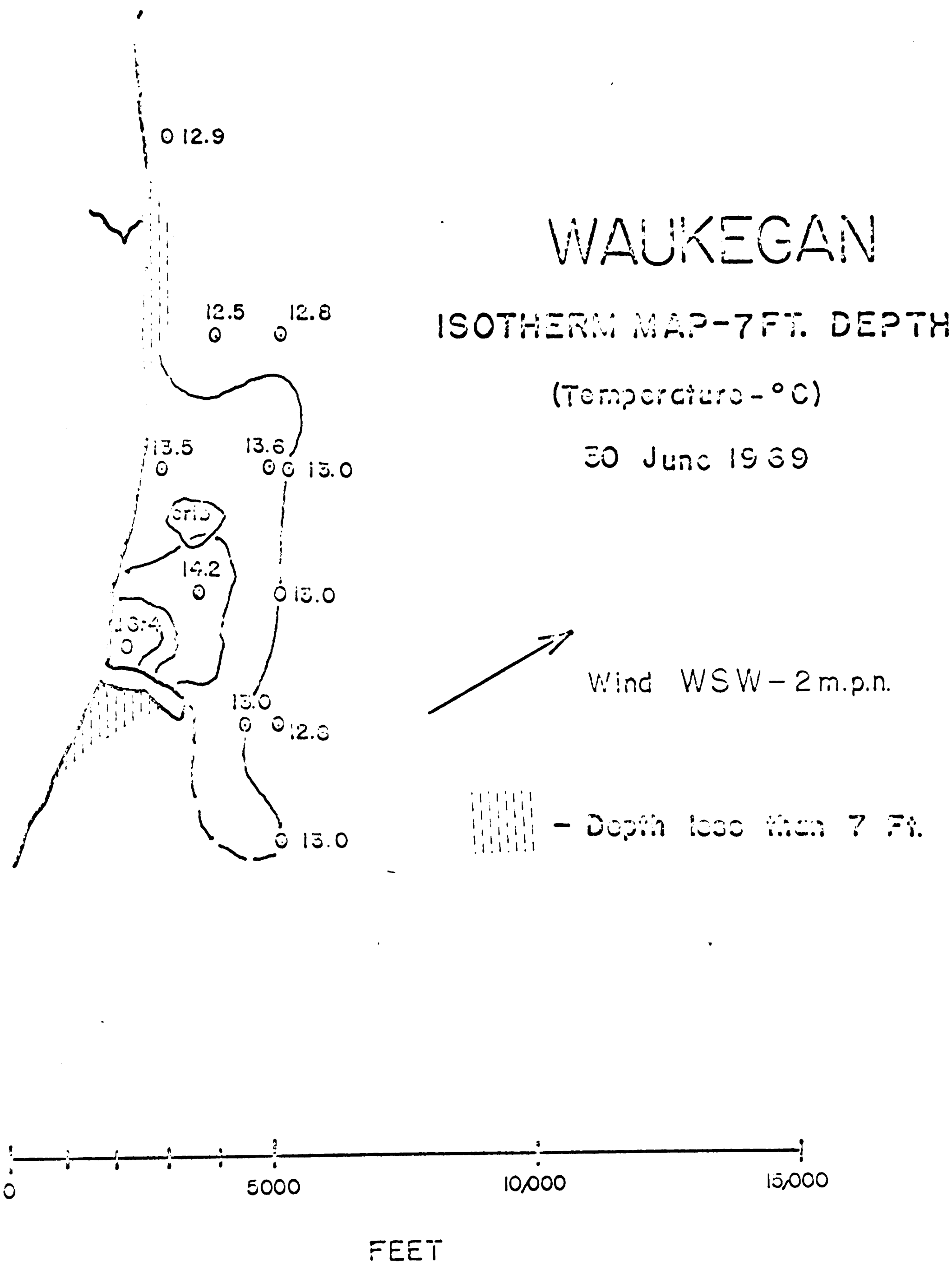
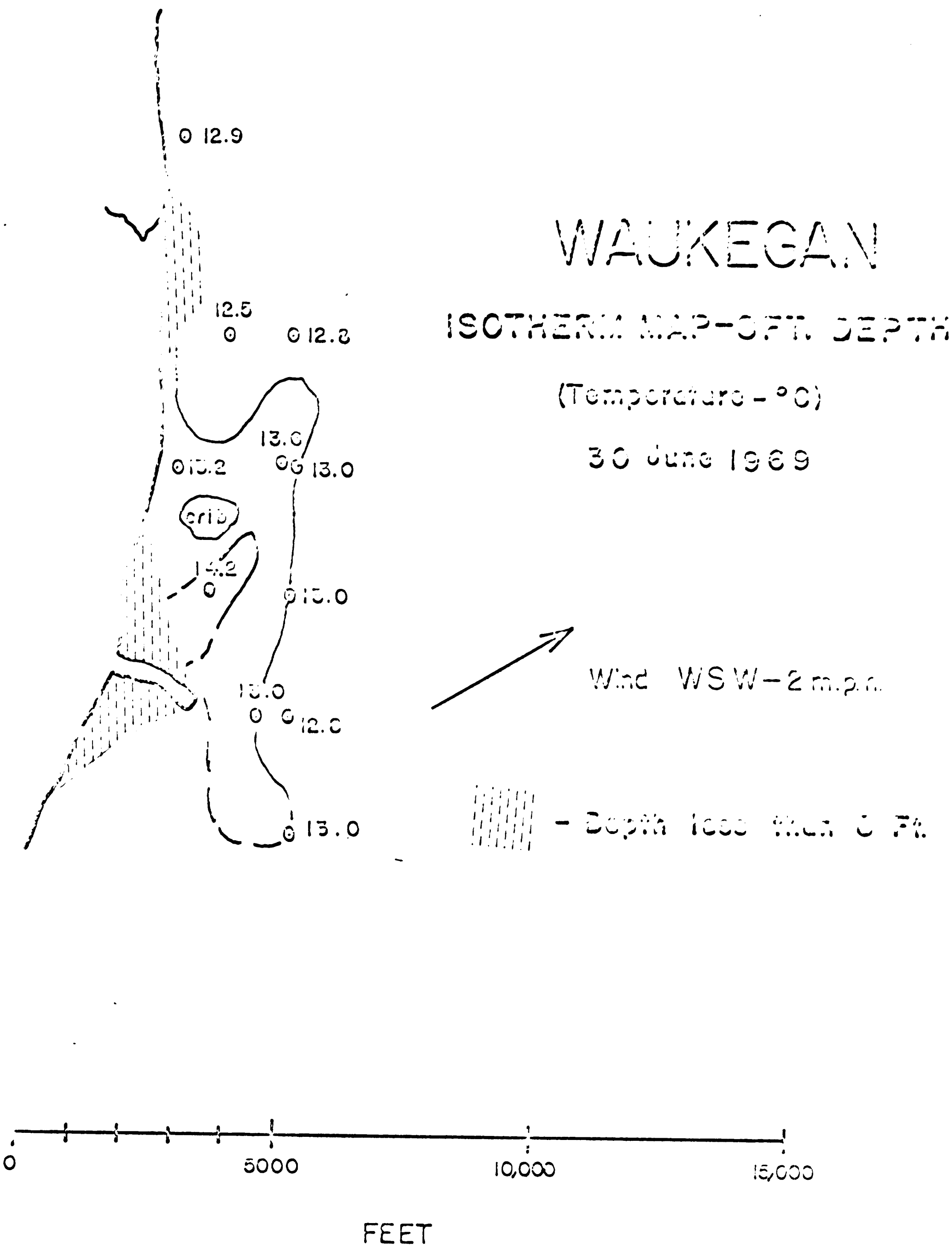
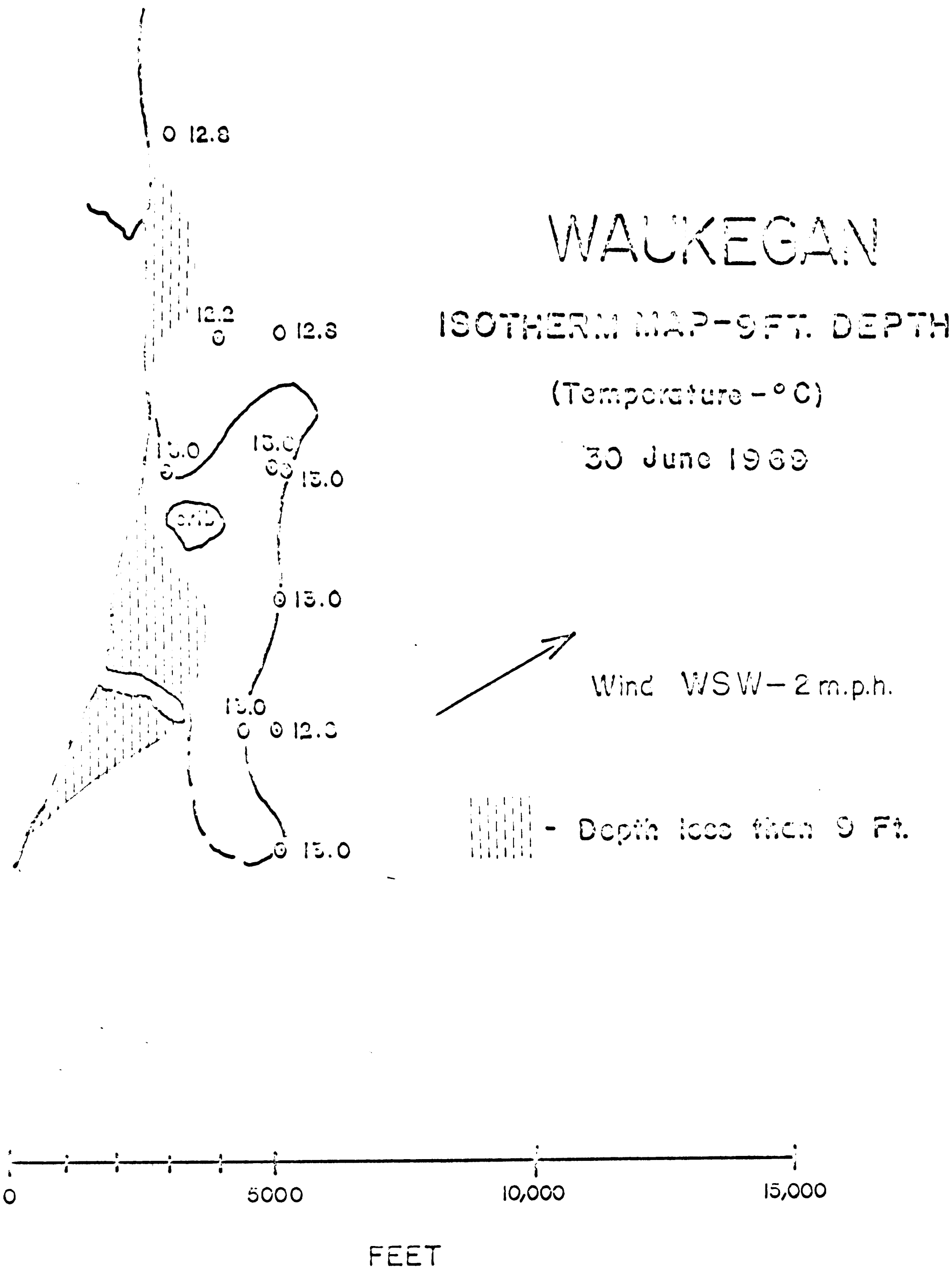

WAUKEGAN
ISOTHERM MAP-7FT. DEPTH
(Temperature - °C)
30 June 1969
12.9
12.5
12.8
13.5
13.6
13.0
14.2
13.0
13.0
12.8
13.0
Wind WSW - 2 m.p.h.
- Depth less than 7 Ft.
0
5000
10,000
15,000
FEET

Figure 21



WAUKEGAN
ISOTHERM MAP-0FT. DEPTH
(Temperature - °C)
30 June 1969
12.9
12.5
12.8
13.0
13.0
crib
14.2
13.0
13.0
Wind WSW - 2 m.p.h.
- Depth less than
0
5000
10,000
15,000
FEET

Figure 22



WAUKEGAN
ISOTHERM MAP-9 FT. DEPTH
(Temperature - °C)
30 June 1969
12.8
12.2
12.8
Wind WSW-2 m.p.h.
- Depth less than 9 Ft.
0
5000
10,000
15,000
FEET

Table 8

Waukegan

Water Temperature Data
30 June 1969

Sta. WP-1

Surface	-	16.6°C	61.9°F
1 ft. depth	-	16.5	61.7
2 ft. "	-	16.5	61.7
3 ft. "	-	16.5	61.7
4 ft. "	-	16.5	61.7
5 ft. "	-	16.5	61.7
6 ft. "	-	16.4	61.5
7 ft. "	-	16.4	61.5

Sta. WP-2

Surface	-	12.8°C	55.0°F
1 ft. depth	-	12.6	54.7
2 ft. "	-	12.6	54.7
3 ft. "	-	12.6	54.7
4 ft. "	-	12.6	54.7
5 ft. "	-	12.6	54.7
6 ft. "	-	12.6	54.7

Sta. WP-3

Surface	-	13.0°C	55.4°F
1 ft. depth	-	13.0	55.4
2 ft. "	-	13.0	55.4
3 ft. "	-	13.0	55.4
4 ft. "	-	13.0	55.4
5 ft. "	-	13.0	55.4
6 ft. "	-	13.0	55.4
7 ft. "	-	13.0	55.4
8 ft. "	-	13.0	55.4
9 ft. "	-	13.0	55.4
10 ft. "	-	13.0	55.4
11 ft. "	-	13.0	55.4
12 ft. "	-	12.8	55.0
13 ft. "	-	12.8	55.0
14 ft. "	-	12.8	55.0
15 ft. "	-	12.8	55.0
16 ft. "	-	12.8	55.0
17 ft. "	-	12.8	55.0
18 ft. "	-	12.6	54.7
19 ft. "	-	12.6	54.7

Sta. WP-4, 1/4 mile East of outfall channel

Surface	-	12.8°C	55.0°F
1 ft. depth	-	12.8	55.0
2 ft. "	-	12.8	55.0

Sta. WP-4 (Cont.)

3 ft. depth	-	12.8°C	55.0°F
4 ft. "	-	12.8	55.0
5 ft. "	-	12.8	55.0
6 ft. "	-	12.8	55.0
7 ft. "	-	12.8	55.0
8 ft. "	-	12.8	55.0
9 ft. "	-	12.8	55.0
10 ft. "	-	12.8	55.0
11 ft. "	-	12.8	55.0
12 ft. "	-	12.8	55.0
13 ft. "	-	12.8	55.0
14 ft. "	-	12.8	55.0
15 ft. "	-	12.8	55.0
16 ft. "	-	12.8	55.0
17 ft. "	-	12.8	55.0
18 ft. "	-	12.8	55.0

Sta. WP-5, 1/2 mile North of WP-4

Surface	-	13.0°C	55.4°F
1 ft. depth	-	13.0	55.4
2 ft. "	-	13.0	55.4
3 ft. "	-	13.0	55.4
4 ft. "	-	13.0	55.4
5 ft. "	-	13.0	55.4
6 ft. "	-	13.0	55.4
7 ft. "	-	13.0	55.4
8 ft. "	-	13.0	55.4
9 ft. "	-	13.0	55.4
10 ft. "	-	13.0	55.4
11 ft. "	-	13.0	55.4
12 ft. "	-	13.0	55.4
13 ft. "	-	13.0	55.4
14 ft. "	-	13.0	55.4
15 ft. "	-	13.0	55.4
16 ft. "	-	13.0	55.4
17 ft. "	-	13.0	55.4
18 ft. "	-	12.9	55.2
19 ft. "	-	12.9	55.2
20 ft. "	-	12.9	55.2
21 ft. "	-	12.9	55.2
22 ft. "	-	12.9	55.2
23 ft. "	-	12.9	55.2
24 ft. "	-	12.8	55.0
25 ft. "	-	12.8	55.0
26 ft. "	-	12.8	55.0
27 ft. "	-	12.8	55.0

Sta. WP-6, 1/2 mile North of WP-5

Surface	-	13.0°C	55.4°F
1 ft. depth	-	13.0	55.4
2 ft. "	-	13.0	55.4
3 ft. "	-	13.0	55.4
4 ft. "	-	13.0	55.4
5 ft. "	-	13.0	55.4
6 ft. "	-	13.0	55.4
7 ft. "	-	13.0	55.4
8 ft. "	-	13.0	55.4
9 ft. "	-	13.0	55.4
10 ft. "	-	13.0	55.4
11 ft. "	-	13.0	55.4
12 ft. "	-	12.8	55.0
13 ft. "	-	12.8	55.0
14 ft. "	-	12.8	55.0
15 ft. "	-	12.8	55.0
16 ft. "	-	12.8	55.0
17 ft. "	-	12.6?	
18 ft. "	-	12.8	55.0
19 ft. "	-	12.8	55.0
20 ft. "	-	12.8	55.0
21 ft. "	-	12.8	55.0
22 ft. "	-	12.8	55.0
23 ft. "	-	12.8	55.0
24 ft. "	-	12.8	55.0
25 ft. "	-	12.8	55.0
26 ft. "	-	12.8	55.0
27 ft. "	-	12.5	54.5
28 ft. "	-	12.0	53.6
29 ft. "	-	12.0	53.6

Sta. WP-7, 1/2 mile North of WP-6

Surface	-	13.0°C	55.4°C
1 ft. depth	-	13.0	55.4
2 ft. "	-	13.0	55.4
3 ft. "	-	13.0	55.4
4 ft. "	-	13.0	55.4
5 ft. "	-	13.0	55.4
6 ft. "	-	12.8	55.0
7 ft. "	-	12.8	55.0
8 ft. "	-	12.8	55.0
9 ft. "	-	12.8	55.0
10 ft. "	-	12.8	55.0
11 ft. "	-	12.8	55.0
12 ft. "	-	12.8	55.0
13 ft. "	-	12.8	55.0
14 ft. "	-	12.8	55.0
15 ft. "	-	12.8	55.0
16 ft. "	-	12.8	55.0
17 ft. "	-	12.8	55.0
18 ft. "	-	12.8	55.0
19 ft. "	-	12.8	55.0
20 ft. "	-	12.8	55.0

Sta. WP-7 (Cont.)

21 ft. depth	-	12.8°C	55.0°F
22 ft. "	-	12.8	55.0
23 ft. "	-	12.8	55.0
24 ft. "	-	12.8	55.0
25 ft. "	-	12.8	55.0
26 ft. "	-	12.8	55.0
27 ft. "	-	12.8	55.0
28 ft. "	-	12.8	55.0
29 ft. "	-	12.8	55.0
30 ft. "	-	12.8	55.0
31 ft. "	-	12.8	55.0

Sta. WP-8, halfway to shore from WP-7

Surface	-	12.8°C	55.0°F
1 ft. depth	-	12.8	55.0
2 ft. "	-	12.8	55.0
3 ft. "	-	12.8	55.0
4 ft. "	-	12.8	55.0
5 ft. "	-	12.8	55.0
6 ft. "	-	12.6	54.7
7 ft. "	-	12.5	54.5
8 ft. "	-	12.5	54.5
9 ft. "	-	12.2	54.0
10 ft. "	-	12.2	54.0
11 ft. "	-	12.2	54.0
12 ft. "	-	12.2	54.0
13 ft. "	-	12.0	53.6
14 ft. "	-	12.0	53.6

Sta. WP-9, direction - towards shore from WP-8, location - as close to shore as possible (approx. 100 yds. from shore)

Surface	-	13.6°C	56.5°F
1 ft. depth	-	13.4	56.1
2 ft. "	-	13.2	55.8
3 ft. "	-	13.2	55.8
4 ft. "	-	13.0	55.4
5 ft. "	-	13.0	55.4
6 ft. "	-	13.0	55.4

Sta. WP-10, 3/4 mile North of WP-9

Surface	-	13.0°C	55.4°F
1 ft. depth	-	13.0	55.4
2 ft. "	-	13.0	55.4
3 ft. "	-	13.0	55.4
4 ft. "	-	13.0	55.4
5 ft. "	-	13.0	55.4
6 ft. "	-	13.0	55.4
7 ft. "	-	12.9	55.2
8 ft. "	-	12.9	55.2
9 ft. "	-	12.8	55.0

Sta. WP-10 (Cont.)

10 ft. depth	-	12.8°C	55.0°F
11 ft. "	-	12.8	55.0

Sta. WP-11, 1/2 mile South of WP-9

Surface	-	14.0°C	57.2°F
1 ft. depth	-	14.0	57.2
2 ft. "	-	14.0	57.2
3 ft. "	-	14.0	57.2
4 ft. "	-	13.8	56.8
5 ft. "	-	13.6	56.5
6 ft. "	-	13.6	56.5
7 ft. "	-	13.5	56.3
8 ft. "	-	13.2	55.8
9 ft. "	-	13.0	55.4

Sta. WP-12, 1/2 mile from shore, outside WP-11

Surface	-	14.0°C	57.2°F
1 ft. depth	-	13.8	56.8
2 ft. "	-	13.8	56.8
3 ft. "	-	13.8	56.8
4 ft. "	-	13.8	56.8
5 ft. "	-	13.8	56.8
6 ft. "	-	13.6	56.5
7 ft. "	-	13.6	56.5
8 ft. "	-	13.6	56.5
9 ft. "	-	13.6	56.5
10 ft. "	-	13.6	56.5
11 ft. "	-	13.6	56.5
12 ft. "	-	13.0	55.4
13 ft. "	-	13.0	55.4
14 ft. "	-	13.0	55.4
15 ft. "	-	12.9	55.2
16 ft. "	-	12.9	55.2
17 ft. "	-	12.9	55.2
18 ft. "	-	12.9	55.2
19 ft. "	-	12.9	55.2
20 ft. "	-	12.8	55.0
21 ft. "	-	12.8	55.0
22 ft. "	-	12.6	54.7
23 ft. "	-	12.4	54.3
24 ft. "	-	12.4	54.3

Sta. WP-13, halfway to shore from WP-5

Surface	-	14.9°C	58.8°F
1 ft. depth	-	14.8	58.6
2 ft. "	-	14.8	58.6
3 ft. "	-	14.8	58.6
4 ft. "	-	14.6	58.3
5 ft. "	-	14.6	58.3
6 ft. "	-	14.2	57.6
7 ft. "	-	14.2	57.6
8 ft. "	-	14.2	57.6

Sta. WP-14, halfway to outfall lite from WP-4

Surface	-	13.0°C	55.4°F
1 ft. depth	-	13.0	55.4
2 ft. "	-	13.0	55.4
3 ft. "	-	13.0	55.4
4 ft. "	-	13.0	55.4
5 ft. "	-	13.0	55.4
6 ft. "	-	13.0	55.4
7 ft. "	-	13.0	55.4
8 ft. "	-	13.0	55.4
9 ft. "	-	13.0	55.4
10 ft. "	-	13.0	55.4
11 ft. "	-	13.0	55.4
12 ft. "	-	13.0	55.4
13 ft. "	-	13.0	55.4
14 ft. "	-	13.0	55.4

(Table 9) to 5,979,000 in the outfall (Table 10.) There was no evidence of heat-stimulated recovery in numbers in the early part of the plume; phytoplankton numbers fell from 5,979,000 cells per liter in the outfall to 3,558,000 at Station WP-13 in the plume (Table 11).

In the intake water zooplankton (Table 12) averaged 12.45 organisms per liter but their numbers fell off to 10.48 in the outfall and many dead and broken organisms were observed in the material from this station. Continued die-off from passage through the plant is deduced from the further decline of zooplankton numbers to 2.29 at Station WP-13 in the plume. Not only did total numbers diminish, but the numbers of each of the dominant organisms declined steadily through these three stations.

Benthos (Table 13) at Waukegan were so sparse that little can be made of the results. The difference in numbers from intake to outfall is within the range of variation of the method. The increased numbers of amphipods at Station WP-13 probably reflects nothing more than enough reduction in outflow current to enable these weakly-swimming creatures to remain there.

In summary, the biological data show kill-off of both phytoplankton and zooplankton in passage through the plant. In both types of plankton there appears to have been continuation of die-off between the outfall and the nearby portion of the plume. Benthos results show nothing attributable to the presence of the plant except washing-out due to currents in the intake and outfall.

Micrometeorological Measurements

At Station MCP-15 in Michigan City harbor on 28 June 1969 near, but east of, MCP-8 in plume water of 21.6°C, we floated a buoyed temperature staff upon which Yellow Springs Thermistors Model No. 401 were mounted at heights of 4, 8, 16, and 24 inches above the water surface. A fifth thermistor measured the surface water temperature.

Table 9

Phytoplankton

Station WP-2, in front of intake, Waukegan Generating Station
30 June 1969
Light SW breeze

Organism	No. of Colonies	Cells per Liter
Asterionella spp.	13,739	85,870
Diatoma spp.	87,587	662,916
Nitzschia spp.	---	42,935
Tabellaria spp.	238,719	1,569,704
Synedra spp.	---	346,915
Melosira spp.	140,827	1,008,114
Fragilaria crotonensis	66,979	1,707,096
Fragilaria capucina	6,870	901,635
Oscillatoria spp.	---	125,370
Rhizosolenia spp.	---	94,457
Cyclotella spp.	---	29,196
Gomphosphaeria spp.	---	---
Closteriopsis longissima	---	---
Cymatopleura spp.	---	5,152
Dinobryon spp.	8,587	51,522
Navicula sp.	---	1,717
Pediastrum spp.	---	---
Stephanodiscus niagarae	---	---
		6,632,000

Table 10

Phytoplankton

Station WP-1, in outfall channel, Waukegan Generating Station
30 June 1969
Light SW breeze

Organism	No. of Colonies	Cells per Liter
Asterionella formosa	5,152	33,488
Diatoma tenue	64,400	714,840
Nitzschia spp.	---	12,880
Tabellaria fenestrata	193,200	1,795,472
Synedra spp.	---	414,736
Melosira spp.	103,040	1,108,968
Fragilaria crotonensis	64,400	1,455,440
Fragilaria capucina	2,576	176,456
Oscillatoria spp.	---	10,690
Rhizosolenia spp.	---	95,312
Cyclotella spp.	---	43,792
Gomphosphaeria spp.	---	---
Closteriopsis longissima	---	---
Cymatopleura spp.	---	---
Dinobryon spp.	9,016	112,056
Navicula sp.	---	1,288
Pediastrum sp.	---	1,288
Stephanodiscus niagarae	---	2,576
		5,979,000

Table 11

Phytoplankton

Station WP-13, in the plume, Waukegan Generating Station
30 June 1969
Light SW breeze

Organism	No. of Colonies	Cells per Liter
Asterionella formosa	8,430	47,770
Diatoma tenue	68,845	352,655
Nitzschia spp.	---	16,860
Tabellaria fenestrata	164,385	1,201,275
Synedra ulna	---	241,660
Melosira granulata & M. binderana combined	57,605	592,910
Fragilaria crotonensis	30,910	771,345
Fragilaria capucina	4,215	126,450
Oscillatoria spp.	---	54,795
Rhizosolenia eriense	---	71,655
Cyclotella spp.	---	44,960
Gomphosphaeria spp.	---	2,810
Closteriopsis longissima	---	2,810
Cymatopleura spp.	---	1,405
Dinobryon spp.	2,810	29,505
Navicula spp.	---	---
Pediastrum spp.	---	---
Stephanodiscus niagarae	---	---
		3,558,000

Table 12

POWER PLANT SURVEYS - PRIMARY ZOOPLANKTON COUNTS

Waukegan Plant, Lake Michigan (No. Org./Liter)

	WP-1 Outfall	WP-2 Intake	WP-13 In plume
CALANOID COPEPODS:			
Diaptomus sp.	5.56	5.97	0.98
Others	Eurytemora affinis 0.05		
CYCLOPOID COPEPODS	3.80	5.02	0.91
ROTIFERS:			
Asplanchna sp.	0.42	0.52	0.20
(Other spp. are too small for this net)			
CLADOCERA:			
Bosmina sp.	0.56	0.94	0.20
Leptodora kindtii	0.09		
OTHER GROUPS:			
REMARKS:	Many dead and broken orgs.		

Table 13

Benthos, numbers per meter^2

Waukegan Generation Station
30 June 1969

Station	Amphipods	Oligochaetes	Sphaeriidae	Tendipedidae	Others
WP-1 outfall	8	17	0	0	0
WP-2 intake	0	17	0	0	0
WP-13 plume	86	0	0	8	0

During a short period of free drift the thermistors (which were all calibrated to read the same temperature at the same level) read:

24" Over water	-----	24.4°
16" " "	-----	24.9°
8" " "	-----	24.5°
4" " "	-----	24.1°
Water surface	-----	21.6°

We can attribute to this series of temperature readings nothing more than that the air became cooler nearer the water. The half-degree drop of temperature at 24" cannot at present be either disproved or explained.

On 30 June 1969 in the outfall channel of the Waukegan Generating Station three successive runs with the air temperature staff were carried out. The first two were successive readings during one drift from well up in the outfall channel; the third was a repeat run after steaming back up the channel (perhaps a little further than the first time). The results are tabulated below:

	Run 1	drift out	Run 2	run back up	Run 3
24" Over water	21.2°C		20.9°C		21.0°C
16" " "	21.8		20.9		21.0
8" " "	21.2		20.5		20.5
4" " "	20.5		20.0		20.1
Water surface	16.0		15.5		16.1

The immediate results of these data again indicate only that the air became cooler nearer the water. On Run 1 the thermistor at 24 inches read lower than the one at 16"; this was not true on Runs 2 and 3. We have tried to, but cannot, ascribe the behavior of the 24" thermistor to some inherent difference of its own. When the thermistors were coiled at the same level in a covered tub in the ship's laboratory, this sensed the same temperature as the others. After being mounted on the staff, and with the staff lying horizontally on the deck in the open air, this thermistor read the same temperature as the others.

As these micrometeorological data were further contemplated there came to light the possibility that warmer air next to the warm plume water need not be expected. The transfer of sensible heat from plume water to air may be demonstrable only as less rapid vertical cooling in the bottom of the air column over the plume water, in comparison to that in the bottom of the air column over ambient lake water outside the plume. This will be assessed in 1970 by floats of the air temperature staff in lines transverse to plume axes. From these temperature readings the rates of vertical cooling in the bottom of the air column over the plume may be compared to cooling rates in the bottom of the air column at positions outside the plume. Such experiments will at least answer our lingering doubts as to whether the present Yellow Springs thermistors are sufficiently sensitive to provide answers to this type of question.

On 30 June in the outer end of the outfall channel at Waukegan we tried to use a Bendix Model 566-3 Psychron aspirated psychrometer to determine whether local differences in relative humidity could be found near warm plume water. The instrument ventilates its wet and dry bulbs electrically and may be sensitive enough for the purpose, but it requires visual readings of the thermometers. The tallest man on the ship was able, by lying down, kneeling, stooping, standing erect, and standing upon a box, to read the two thermometers at each foot of altitude from 1 through 6 feet above the water. The results are tabulated below:

Height	Dry Bulb	Wet Bulb	dT	Relative Humidity
1 ft	22.0°C	20.5°C	1.5°C	87%
2	22.0	20.3	1.7	86
3	21.7	20.0	1.7	86
4	21.9	20.2	1.7	86
5	22.0	20.5	1.5	87
6	22.4	20.6	1.8	85

The resulting relative humidities have variations that may be within the range of error of the instrument under ideal conditions for reading the thermometers. They are considered meaningless under the conditions of difficult posture and need for speed that were involved in the field conditions.

A remote-reading and recordable dew-point sensor has been found and will be tried during the spring and early summer of 1970. This instrument is capable, in the laboratory, of detecting significant difference between the dew-point and relative humidity of air close above the rim of a container, half full of water, and air in the upper half of the container below the rim. This sensor is readily adaptable to mechanical raising and lowering at reasonable distance from the ship's side in the upwind airflow. The readings would then not be modified by the presence of the ship. The instrument will be used in traverses across plume axes to determine whether variations in dew-point or relative humidity can be shown between conditions in the axis of the plume and the ambient water on either side of the plume. If it can detect such variations in the field, it will be used to map the over-plume vs over-ambient dew-point and relative humidity conditions in three dimensions.

In summary, our present thermistor temperature sensors may or may not be able to demonstrate the flow of sensible heat from plume water to air. If heat flow can be measured, it will be by showing differences in vertical rates of cooling in the bottoms of air columns over plumes vs the conditions in the bottoms of air columns over ambient water outside the plumes. If traverses across plumes cannot show different air cooling rates over the plume and outside, we will have to go to different sensors; the very sensitive thermocouples are an obvious first choice. Our standard aspirated psychrometer may be sufficiently sensitive to demonstrate increased flux of water from plume to air, but it is ruled out by requiring the presence of the human eye at the same altitude.

Putting a man on a variable-height device at sufficient distance outboard so the ship will not influence the air measurements is impractical. A new sensor will be tried.

COOK PLANT PREOPERATIONAL STUDIES

Our 1966 surveys of bottom sediments and benthos around the Cook site showed the bottom to be sampleable, and indicated, everywhere except in a wave-washed belt along the beach, a benthos population of numbers and composition comparable to other inshore areas of Lake Michigan. The grid of sampling stations used in the 1966 survey did not adequately define the width of an inshore belt of benthos scarcity, hereafter called the "sterile zone."

On 25 April 1969 the R/V INLAND SEAS occupied a series of benthos stations in 15, 25, and 35 feet of depth along east-west lines extending from shore off the center of the plant site and off positions 1.25, 2.5, and 5 miles to the north and to the south of the plant site center. The purpose of these stations was to determine the density of sampling needed to adequately define the width of the benthos "sterile zone" along the beach. The station locations and the benthos counts are presented in Figures 23 through 26. The results indicate quite clearly that a station in 15 feet of water will adequately sample the "sterile zone." They also show that, except at Station PPP-2, no amphipods were present at 25 feet, though oligochaetes were present in small numbers at this depth in most stations. In view of this it has been decided that sampling at 15 and 30 feet of depth (nearly 1/4 and 1/2 mile from shore) on courses perpendicular to shore, instead of west by compass, will adequately sample the "sterile zone." This will also allow minimal error from contouring as benthic organisms come into the picture as water depth increases.

Phytoplankton, zooplankton, and benthos results are given in Tables 14 through 22.

The phytoplankton results show some of the common characteristics of Lake Michigan spring collections. The dominant species in spring are diatoms. The populations, in cells per liter, become greater close to shore. The undesirable

Figure 23

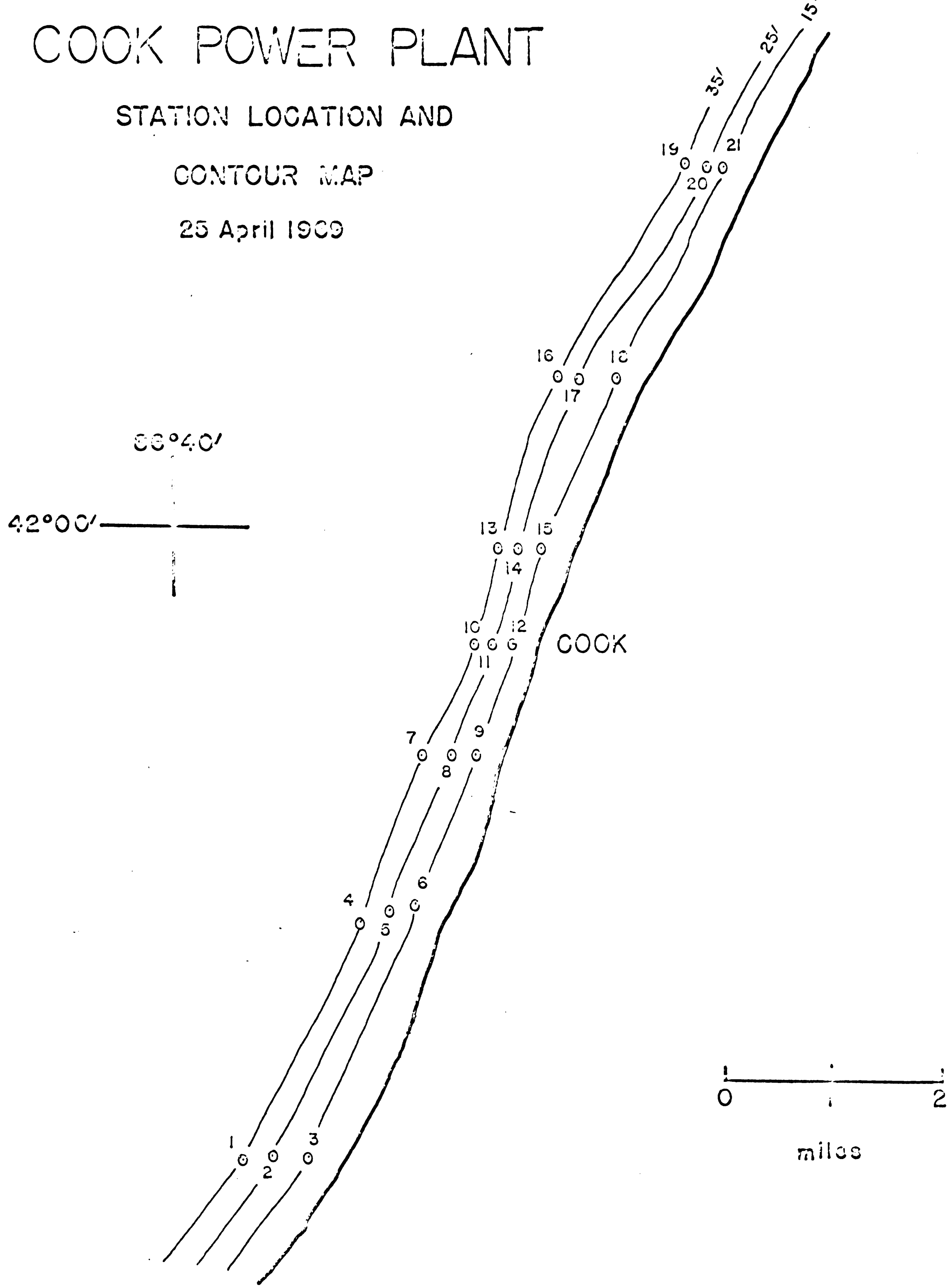

COOK POWER PLANT
STATION LOCATION AND
CONTOUR MAP
25 April 1969
86°40'
42°00'
35'
25'
15'
COOK
0
2
miles
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21

Figure 24

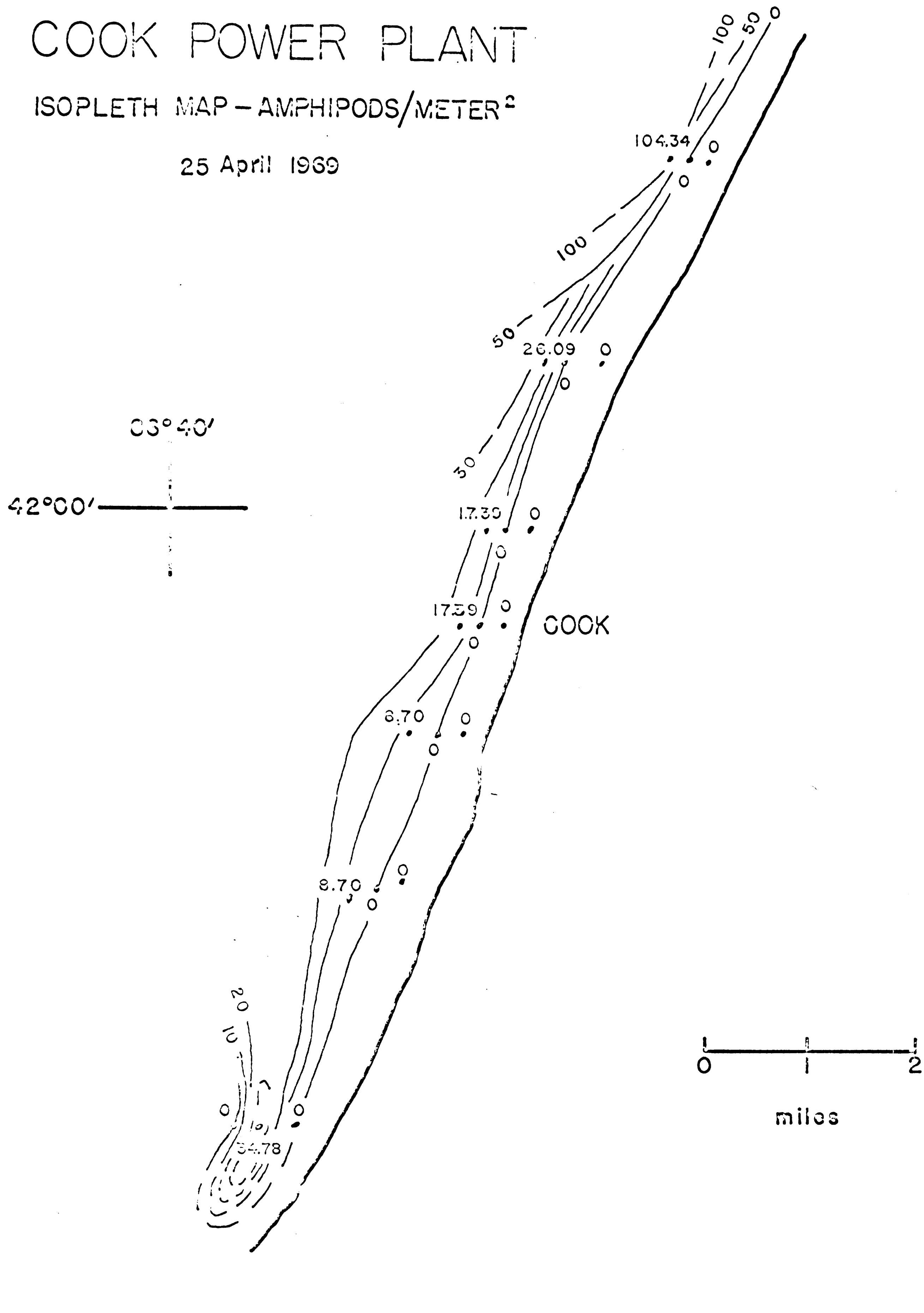
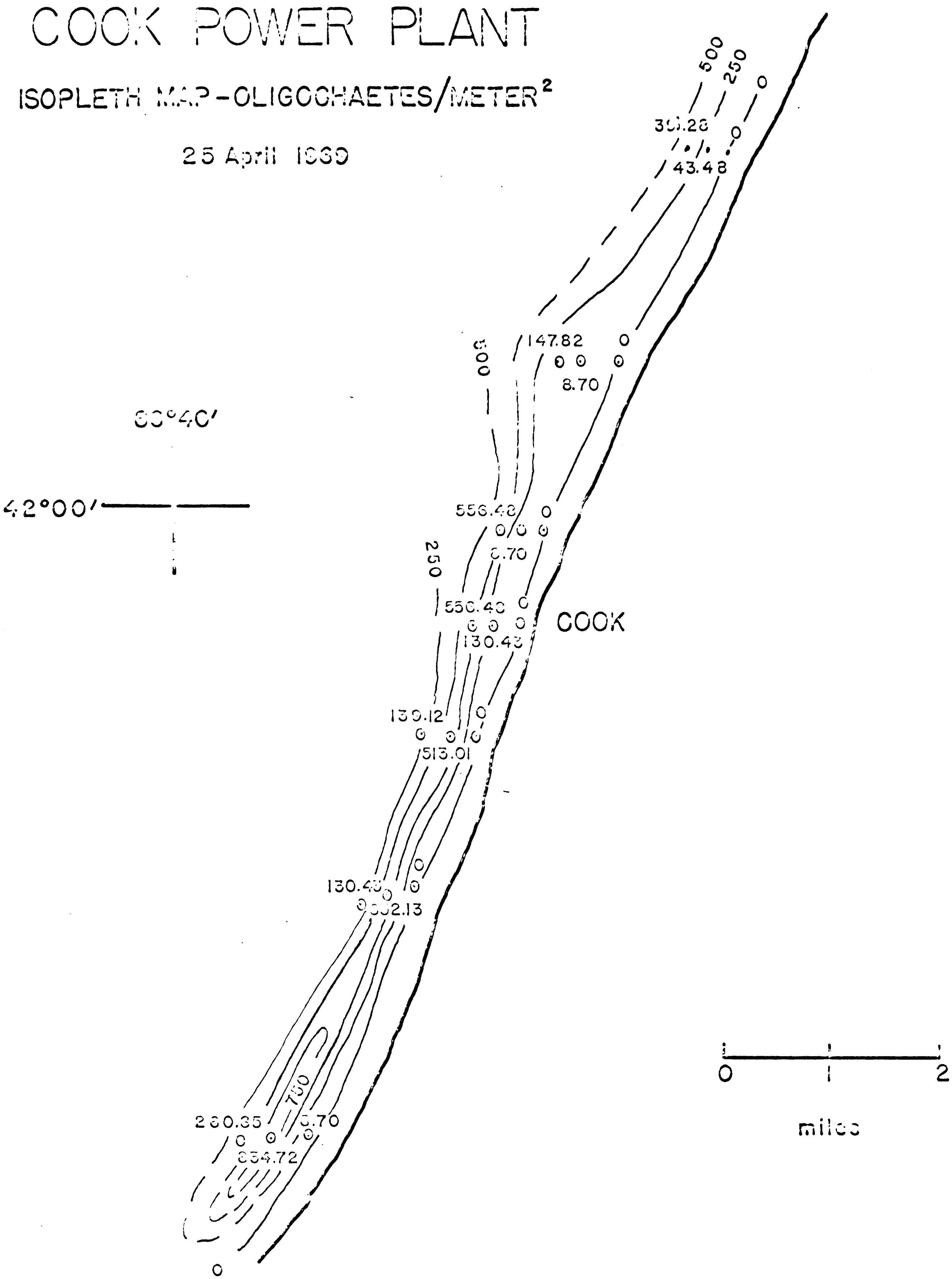

COOK POWER PLANT
ISOPLETH MAP – AMPHIPODS/METER²
25 April 1969
42°00'
COOK
104.34
26.09
17.39
17.39
8.70
8.70
34.78
100
50
30
20
10
0
1
2
miles

Figure 25



COOK POWER PLANT
ISOPLETH MAP-OLIGOCHAETES/METER²
43.48
147.82
8.70
42°00′
556.48
COOK
130.43
513.01
250
500
750
miles
0
1
2

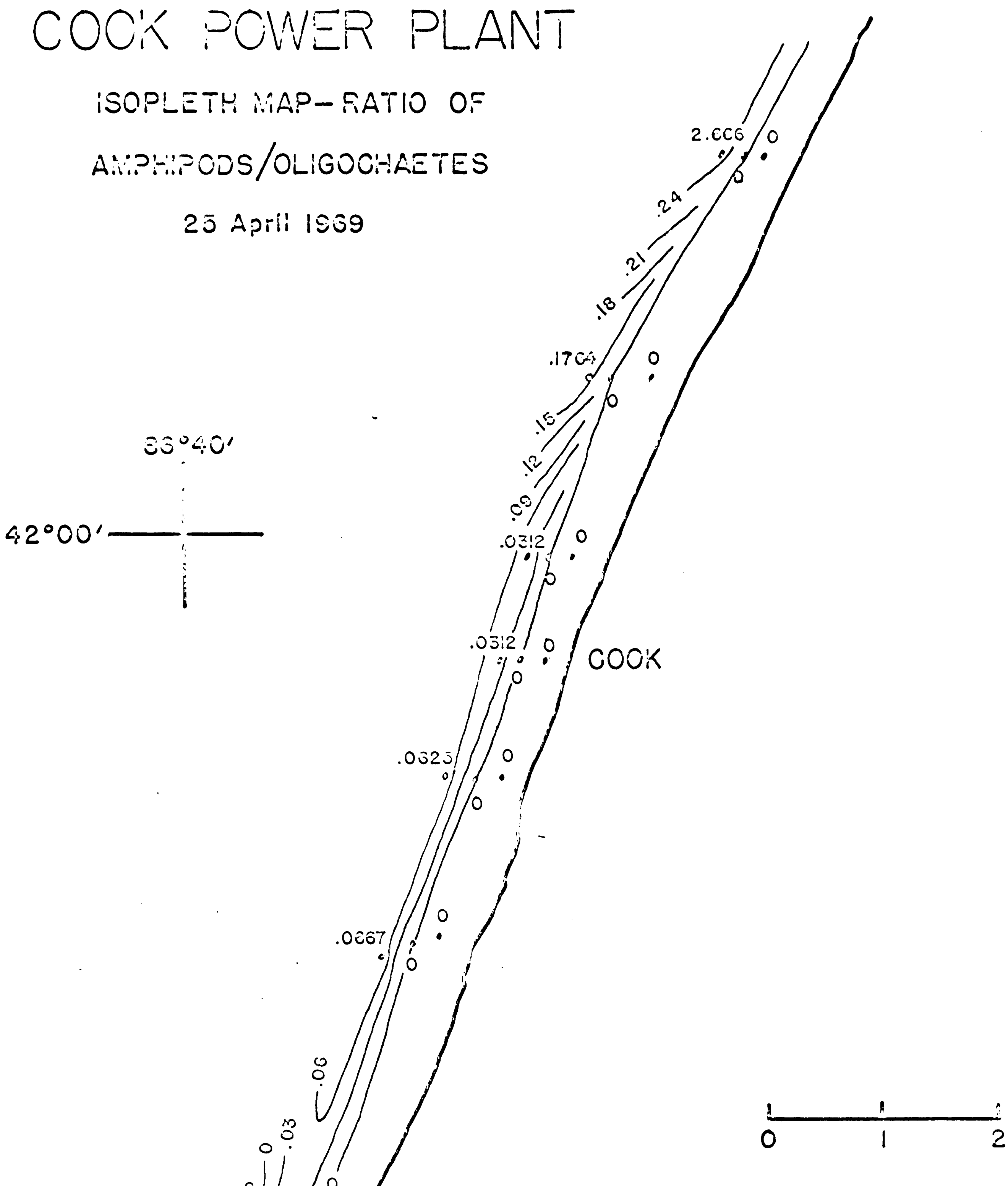

COOK POWER PLANT
ISOPLETH MAP–RATIO OF
AMPHIPODS/OLIGOCHAETES
25 April 1969
86°40′
42°00′
COOK
2.006
.24
.21
.18
.1704
.15
.12
.09
.0312
.0312
.0625
.0667
.06
.03
.0416
0
1
2
miles

Table 14

Phytoplankton Population

Donald C. Cook Plant
25 April 1969

Diatoms:

Synedra acus
Synedra ulna
Asterionella formosa
Asterionella formosa v. gracillima
Tabellaria fenestrata
Fragilaria intermedia
Fragilaria crotonensis
Melosira spp.
Nitzschia spp.
Cyclotella spp.
Navicula spp.
Rhizosolenia spp.
Diatoma vulgarae
Diatoma tenue v. elongatum
Gomphonema spp.
Stephanodiscus spp.

Green Algae:

Ankistrodesmus falcatus
Ankistrodesmus spp.
Spirogyra spp.
Oocystis solitaria
Ulothrix spp.

Yellow-Brown Algae:

Dinobryon divergens
Dinobryon spp.

Blue-Green Algae:

Oscillatoria spp.

Table 15

Phytoplankton

Station PPP-1, Donald C. Cook Plant, Bridgman
25 April 1969

Organism	No. of Colonies	Cells per Liter
Synedra acus	---	35,279
Asterionella formosa	---	2,546
Asterionella formosa v. gracillima	364	1,455
Tabellaria fenestrata	16,730	126,204
Fragilaria intermedia	4,364	174,576
Melosira spp.	9,456	125,477
Fragilaria crotonensis	6,183	92,744
Nitzschia sp.	---	1,819
Synedra ulna	---	25,460
Cyclotella sp.	---	5,819
Ankistrodesmus sp.	---	364
Navicula sp.	---	727
Rhizosolenia sp.	---	727
Dinobryon divergens	364	1,091
Diatoma vulgarae	---	364
Diatoma tenue v. elongatum	1,091	3,640
Oscillatoria sp.	---	727
Spirogyra sp.	---	364
		599,000

Table 16

Phytoplankton

Station PPP-3, Donald C. Cook Plant, Bridgman
25 April 1969

Organism	No. of Colonies	Cells per Liter
Fragilaria intermedia	3,155	96,528
Ankistrodesmus sp.	---	631
Ulothrix sp.	---	1,893
Asterionella formosa	2,524	10,725
Nitzschia sp.	---	3,155
Fragilaria crotonensis	5,047	102,837
Synedra ulna	---	62,459
Tabellaria fenestrata	41,639	381,695
Synedra acus	---	39,747
Diatoma tenue v. elongatum	1,893	8,833
Cyclotella spp.	---	24,605
Melosira spp.	11,356	124,918
Gomphonema sp.	---	631
Oscillatoria sp.	---	631
		859,000

Table 17

Phytoplankton

Station PPP-10, Donald C. Cook Plant, Bridgman
25 April 1969

Organism	No. of Colonies	Cells per Liter
Melosira spp.	2,766	18,532
Nitzschia sp.	---	277
Tabellaria fenestrata	12,447	71,639
Synedra ulna	---	11,894
Synedra acus	---	9,404
Fragilaria crotonensis	1,659	27,936
Cyclotella spp.	---	5,808
Asterionella formosa	277	1,106
Fragilaria intermedia	553	37,064
Diatoma tenue v. elongatum	553	1,936
Navicula sp.	---	277
		185,000

Table 18

Phytoplankton

Station PPP-12, Donald C. Cook Plant, Bridgman
25 April 1969

Organism	No. of Colonies	Cells per Liter
Melosira spp.	4,710	28,260
Gomphonema	---	1,178
Diatoma vulgarae	---	1,178
Synedra acus	---	17,663
Tabellaria fenestrata	48,278	341,475
Synedra ulna	---	47,100
Cyclotella spp.	---	35,325
Oocystis solitaria	---	2,355
Ankistrodesmus falcatus	---	3,533
Fragilaria crotonensis	11,775	80,070
Oscillatoria sp.	---	1,178
Diatoma tenue v. elongatum	1,178	4,710
Nitzschia sp.	---	2,355
Asterionella formosa	1,178	4,710
		571,000

Table 19

Phytoplankton

Station PPP-19, Donald C. Cook Plant, Bridgman
25 April 1969

Organism	No. of Colonies	Cells per Liter
Fragilaria intermedia	868	57,658
Spirogyra sp.	---	695
Synedra acus	---	14,241
Tabellaria fenestrata	24,661	104,202
Synedra ulna	---	15,978
Fragilaria crotonensis	7,120	182,701
Diatoma tenue v. elongatum	868	3,994
Asterionella formosa	---	521
Ankistrodesmus falcatus	---	174
Nitzschia sp.	---	521
Cyclotella spp.	---	7,815
Melosira spp.	4,168	37,860
Asterionella formosa v. gracillima	521	2,258
Stephanodiscus sp.	---	521
Dinobryon sp.	174	521
Oscillatoria spp.	---	695
Rhizosolenia sp.	---	347
		430,000

Table 20

Phytoplankton

Station PPP-21, Donald C. Cook Plant, Bridgman
25 April 1969

Organism	No. of Colonies	Cells per Liter
Nitzschia spp.	---	1,665
Oscillatoria sp.	---	476
Diatoma tenue v. elongatum	476	1,427
Asterionella formosa	476	951
Tabellaria fenestrata	23,304	198,325
Synedra ulna	---	24,731
Synedra acus	---	19,262
Fragilaria crotonensis	6,658	135,784
Fragilaria intermedia	2,854	98,925
Stephanodiscus sp.	---	1,189
Melosira spp.	9,512	53,981
Cyclotella spp.	---	8,323
Rhizosolenia sp.	238	476
		545,000

Table 21

POWER PLANT SURVEYS - PRIMARY ZOOPLANKTON COUNTS

Cook Plant, Lake Michigan (No. Org./Liter)

	PPP-1 35 ft 4/25/69	PPP-3 15 ft 4/25/69	PPP-10 35 ft 4/25/69	PPP-12 15 ft 4/25/69	PPP-19 35 ft 4/25/69	PPP-21 15 ft 4/25/69
CALANOID COPEPODS:						
Diaptomus sp.	0.18	0.37	0.36	2.63	0.23	0.43
Epischura lacustris	0.11		0.01	0.30	0.01	
CYCLOPOID COPEPODS	0.11	0.86	0.32	0.05	0.04	0.08
CLADOCERA:						
Bosmina sp.						0.02

Table 22

Benthos, numbers per meter^2

Donald C. Cook Plant Site
25 April 1969

Station	Amphipods	Oligochaetes	Sphaeriidae	Tendipedidae	Others
PPP-1	0	260.85	26.09	408.67	0
PPP-2	34.78	834.72	52.17	226.07	0
PPP-3	0	8.70	8.70	0	0
PPP-4	8.70	130.43	78.26	199.99	0
PPP-5	0	652.13	8.70	165.21	0
PPP-6	0	0	0	8.70	0
PPP-7	8.70	139.12	269.55	130.43	0
PPP-8	0	513.01	34.78	130.43	0
PPP-9	0	0	0	17.39	0
PPP-10	17.39	556.48	130.43	226.07	0
PPP-11	0	130.43	8.70	86.95	0
PPP-12	0	0	0	8.70	0
PPP-13	17.39	566.48	86.95	434.75	0
PPP-14	0	8.70	8.70	34.78	0
PPP-15	0	0	0	0	0
PPP-16	26.09	147.82	17.39	139.12	0
PPP-17	0	8.70	8.70	8.70	0
PPP-18	0	0	0	0	0
PPP-19	104.34	391.28	43.48	113.04	0
PPP-20	0	43.48	0	52.17	0
PPP-21	0	0	0	0	0

blue-green algae, which "like" warm water, are present in small numbers even in the cold water of spring. Considerably greater populations of phytoplankton were found in the southern and northern lines of stations than were present in the line extending off shore at the Cook plant site; the numbers of phytoplankton cells per liter of water were:

Five miles south	Center of Cook site	Five miles north
Station PPP-3 (15 ft) 859,000 c/l	Station PPP-12 (15 ft) 571,000 c/l	Station PPP-21 (15 ft) 545,000 c/l
Station PPP-1 (35 ft) 599,000 c/l	Station PPP-10 (35 ft) 185,000 c/l	Station PPP-19 (35 ft) 430,000 c/l

In the present state of knowledge, these results have to be interpreted as indicating that waters richer in nutrients lie to the south and to the north of the Cook site. The richer water to the north probably contains decomposed pollutants from the St. Joseph River; the source of nutrients to the south is at present unknown.

The zooplankton collections also indicate populations 2 to 4 times greater in 15 feet of depth than in 35 feet, but this probably means only that the zooplankters move into areas where their phytoplankton food is most abundant.

With the results of these two surveys to work from, attention was turned to developing the best-possible system of sampling stations for the pre- and post-operational aquatic studies around the Cook plant.

Representative and Optimal Sampling at the Cook Site

Six substantial considerations have influenced the development of the sampling system at the stations around the Cook plant site.

First, the system must representatively sample the aquatic and biotic parameters of the environment. "Representatively" here contains the concept of increasing density of samples as one approaches the interest area from any direction.

Second, the system should be optimal in the sense of providing adequate coverage, giving a reasonable economy of sampling time and sample work-up, and be navigationally practical.

Third, currents from the south can bring toward the site water containing higher nutrients from an unknown source. A part of the sampling-station system must, therefore, be located well to the south of the site where the Cook thermal plume would never reach. Similarly, currents from the north will bring toward the site water of damaged quality from the polluted St. Joseph River, necessitating that a part of the sampling system be well to the north beyond reach of the Cook plume. These more remote parts of the system are designed to monitor pollution-caused changes that might wrongly be attributed to effects produced by the Cook plant.

Fourth, a wave-washed zone practically devoid of benthos exists close along the shore. Since both the intake and outfall for the Cook plant will be situated in this "sterile zone," and since this zone will experience the greatest effect of the Cook plume, the shoreward sampling stations must accurately depict and adequately sample this zone both in the preoperation and postoperation periods. The most lakeward parts of the sampling system should lie outside the reach of the Cook plume.

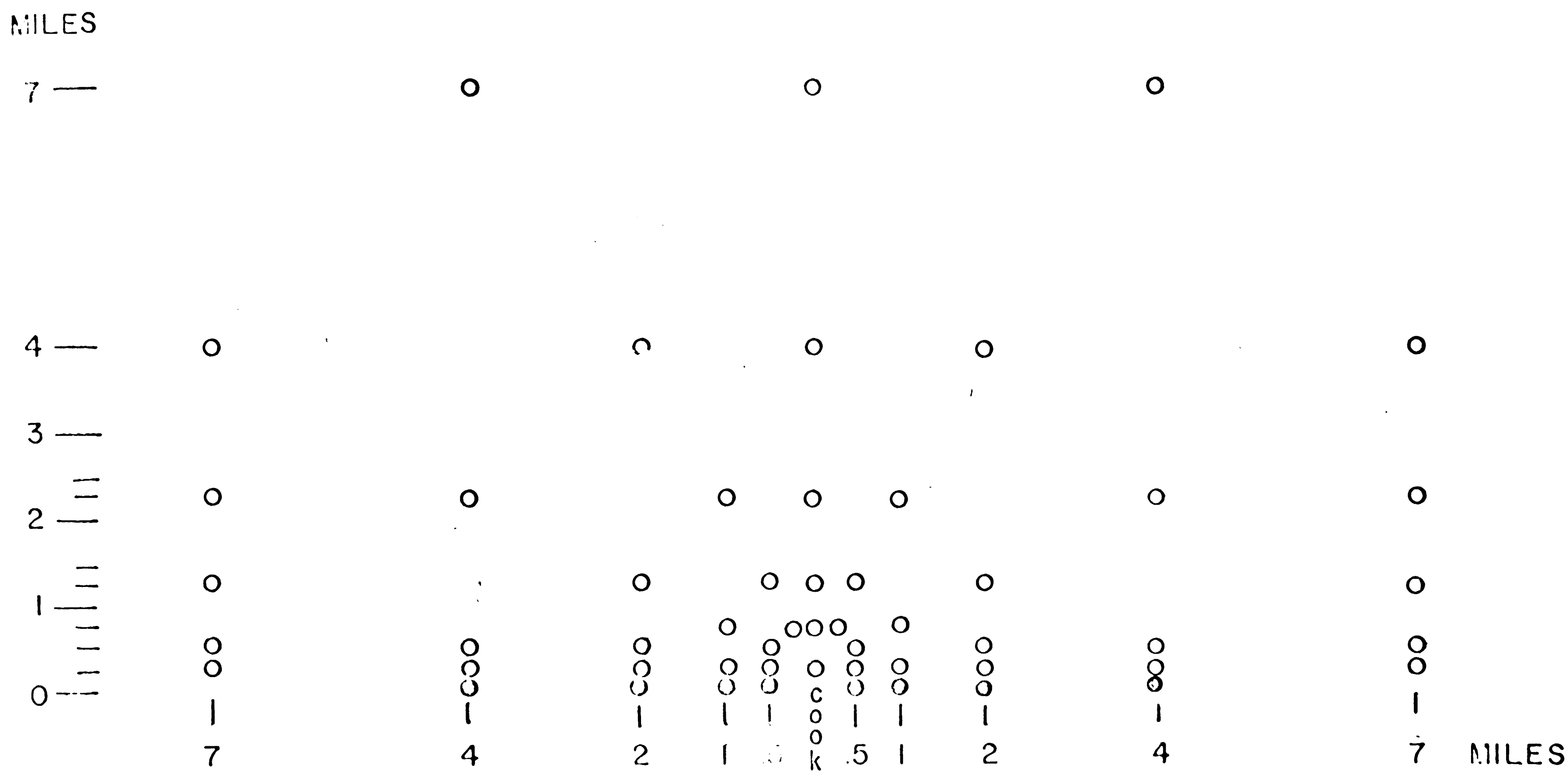
Fifth, the currents which will receive the plant plume are predominantly alongshore currents to the north or to the south. The system of sampling stations must therefore provide for adequate sampling of the plume as it moves north or south along the beach. The north-south station arrangements must also include stations close inshore where the cottagers may observe, or claim to observe blooms of algae that they attribute to Cook plant's waste heat.

Sixth, the system should contain the maximum number of stations at depths which are comparable. On the quite-uniformly sloping bottom off the Cook plant depth is fairly equitable to distance from shore. Except for two most landward rows of sampling stations (at 15 and 30 feet of depth), comparability of depth is taken to be achieved by equal distances from the beach.

From a consideration of all the above points, the system of sampling illustrated in Figure 27 evolved.

Because the Cook plant area is devoid of charted landmarks sufficient to enable the use of sextant fixes, it will be necessary to navigate by radar ranges and bearings. Although the sampling station system is designed to produce an arc with a radius of seven-miles around the outfall of the Cook plant, it is practical to occupy the sampling stations only on courses perpendicular to shore where radar distances to shore and to the St. Joseph pierheads can be used as the primary fix. The radar azimuths to both locations, however, may be used as back-up fixes. We believe that the sampling system proposed meets as well as possible the fundamental design-of-experiments concepts that must be met; we know it meets as well as possible the practical navigational problems; and we think it meets the requirement of concentrating data in critical areas. We will not hesitate to modify it if we acquire evidence that something else is better, but we consider this to be presently the best possible arrangement of sampling stations around the Cook plant. Unless serious objection comes to light before the 1970 ship-operating season, this system of sampling stations will be put into effect in spring (probably May) of 1970 and continue in effect in spring (May), summer (August), and fall (October-November) throughout the preoperational and postoperational surveys needed by the Cook Nuclear Plant.

Figure 27



o = COMPLETE STATION

o =PHYTOPLANKTON ONLY

WILLOW RUN OVERFLIGHT

Ground Truth Conditions for Willow Run Overflight

On 11 August 1969 an aircraft from the University's Willow Run Laboratories made a multi-spectral remote sensing overflight of part of the eastern shore of Lake Michigan from Michigan City, Indiana, to a point north of the Cook plant.

The flight plan for this overflight called for a flight traverse along the shore from Michigan City northward to a point beyond the Cook plant, and a second flight traverse crossing the Cook plant perpendicular to the shore on a lakeward heading. At the time of this flight we occupied a series of six stations in depths from 4 feet to 69 feet and at distances of 200 feet to 2.25 miles off the shore. At three of these stations, CP-1, CP-2, and CP-3 water temperature, depth, water color, and water transparency were measured and phytoplankton collections were made. At Stations CP-1 and CP-2 drogues numbers 3 and 0 were drifted to obtain surface currents. Depth, water color, and water temperature were also obtained at Stations CP-4 through CP-6. The major part of the results from these stations is presented in Figure 28.

Depths between Stations CP-1 and CP-3 are shown along the boat's path; also shown are the direction of movement of drogues #0 and #3. Though the velocity of these drogues are not shown in the figure, they are discussed below.

August 11th was a day of northwest breeze after a substantial northwest blow and as a result the boat experienced a southward set from current. The southeastward current responsible for the set is shown by the 0.36 mph movement of drogue #0 from Station CP-2. Drogue #3, set at Station CP-1, first moved to the southeast then apparently was caught in a narrow alongshore current and carried northward to Station CP-6 where it was recovered aground in 4 feet of water. Not knowing how long it had been aground, no velocity for drogue #3 was computed. Once the current set was realized from the movement of drogue #0, the boat returned to the front of the plant site at CP-4 and ran a corrected course to CP-5 on the offshore leg that the aircraft was expected to fly. At these stations water temperatures, transparencies, and colors did not differ from those at CP-1 and CP-2 therefore additional phytoplankton samples were not taken.

Though the aircraft did not collect usable data along the offshore leg as planned, we are able to report, from the data collected on the traverse alongshore, that in the close-inshore area the surface temperature was 25.0°C. The data collected aboard ship shows the water color was a milky light green, and the water transparency,by Secchi disc transparency measurements was, 1 meter at Stations CP-1, CP-4, and CP-6. At Stations CP-2 and CP-5 the water color was light brownish green, the temperature was 24.0°C, and the transparency was 2.25 meters. At Station CP-3 the surface temperature was 23.5°C; the water color was a light greyish green; and the Secchi disc transparency was 4 meters.

Counts and identifications of the phytoplankton collected at Stations CP-1, CP-2, and CP-3 are given in Tables 22 through 26 below.

While it is impossible to be sure from so limited a survey, it appears that the water at CP-2 may have been a detached mass of St. Joseph River water; at least it had the water color and phytoplankton population characteristic of river water.

Figure 28

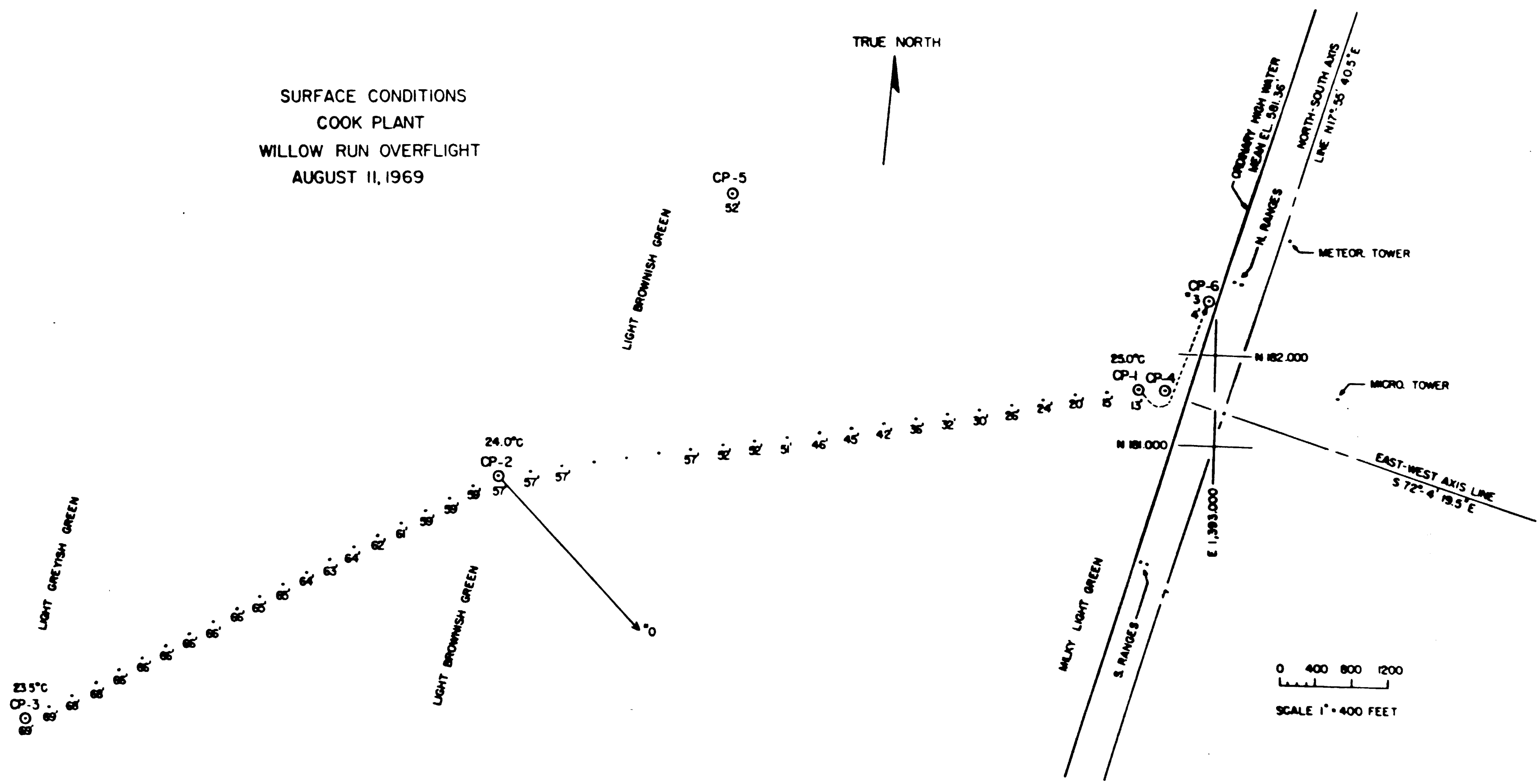

SURFACE CONDITIONS
COOK PLANT
WILLOW RUN OVERFLIGHT
AUGUST 11, 1969
TRUE NORTH
CP-5
CP-6
CP-1
CP-4
CP-2
CP-3
25.0°C
24.0°C
23.5°C
LIGHT BROWNISH GREEN
LIGHT GREYISH GREEN
MILKY LIGHT GREEN
ORDINARY HIGH WATER
MEAN EL 581.36'
NORTH-SOUTH AXIS
LINE N17°35' 40.5"E
N. RANGES
S. RANGES
METEOR. TOWER
MICRO. TOWER
N 182,000
N 181,000
E 1,393,000
EAST-WEST AXIS LINE
S 72° 4' 19.5" E
0 400 800 1200
SCALE 1" = 400 FEET

Table 23

Phytoplankton

Cook Plant Sample Stations
11 August 1969

Diatoms:

Diatoma tenue v. elongatum
Cyclotella sp.
Cyclotella meneghiniana
Fragilaria capucina
Fragilaria crotonensis
Nitzschia sp.
Tabellaria fenestrata
Synedra sp.
Synedra acus
Synedra delicatissima
Synedra ulna
Synedra ostenfeldii
Melosira granulata
Melosira granulata v. augustissima
Melosira binderana
Melosira sp. 1
Navicula sp.
Neidium sp.
Amphora ovalis
Nitzschia acicularis
Nitzschia sp.

Blue-Greens:

Anabaena sp.
Aphanizomenon flos-aquae
Oscillatoria sp.
Phormidium sp.

Greens:

Mougeotia sp.
Shroederia judayi
Oocystis sp.
Oocystis solitaria
Actinastrum hantzschii
Golenkina radiata
Dinobryon divergens
Gleocystis sp.
Cosmarium sp.
Closterium sp.
Ankistrodesmus falcatus
Ulothrix sp.
Pediastrum sp.
Treubaria setigerum
Quadrigula lacustris

Greens: (Cont.)

Tetraedron minimum
Lagerheimia longiseta
Scenedesmus bijuga
Scenedesmus dimorphus
Scenedesmus opoliensis
Scenedesmus quadricauda
Scenedesmus incrassatula
Kirchneriella obesa
Naephrocytium sp.
Crucigenia apiculata
Dictyosphaerium pulchellum
Tetraedron lunula
Tetrastrum sp.
Coelastrum reticulum
Coelastrum sphaericum

Flagellates:

Peridinium sp.
Cryptomonas sp.
Chlamydomonas sp.

Table 24

Phytoplankton

Station CP-1, Cook Plant
11 August 1969

Organism	No. of Colonies	Cells per Liter
Dinobryon divergens		5,568
Ankistrodesmus falcatus		19,488
Peridinium sp.		12,992
Cyclotella sp.		46,400
Oocystis sp.		15,776
Mougeotia sp.		86,403
Golenkinia radiata		1,856
Phormidium sp.		53,824
Gleocystis sp.		1,856
Tetrastrum sp.		928
Melosira granulata	1,856	6,496
Navicula sp.		3,712
Synedra sp.		928
Quadrigula lacustris		928
Cryptomonas sp.		928
Chlamydomonas sp.		5,568
Pediastrum sp.		928
Coelastrum sphaericum		928
Ulothrix sp.		8,352
Anabaena sp.		2,784
Coelastrum reticulum		928
Oscillatoria sp.		928
Neidium sp.		928
Synedra delicatissima		4,640
Synedra ulna		928
Amphora ovalis		928
Synedra ostenfeldii		928
Nitzschia acicularis		928
Naephrocytium sp.		928
Dictyosphaerium pulchellum		1,856
Scenedesmus dimorphus		1,856
Melosira granulata v. augustissima	928	2,784
Fragilaria crotonensis	2,784	18,560
Fragilaria capucina	928	3,712
Tabellaria fenestrata		2,784
		320,000

Table 25

Phytoplankton

Station CP-2, Cook Plant
11 August 1969

Organism	No. of Colonies	Cells per Liter
Shroederia judayi		2,781
Peridinium sp.		66,744
Cryptomonas sp.		30,591
Chlamydomonas sp.		15,759
Oocystis sp.		26,883
Oocystis solitaria		8,343
Cyclotella sp.		305,910
Oscillatoria sp.		16,686
Mougeotia sp.		70,452
Anabaena sp.		7,416
Actinastrum hantzschii		65,817
Golenkinia radiata		1,854
Dinobryon divergens		9,270
Gleocystis sp.		12,051
Cosmarium sp.		2,781
Closterium sp.		2,781
Ankistrodesmus falcatus		36,153
Ulothrix sp.		2,781
Pediastrum sp.		1,854
Treubaria setigerum		2,781
Quadrigula lacustris		927
Tetraedron minimum		927
Lagerheimia longiseta		2,781
Scenedesmus bijuga		1,854
Scenedesmus opoliensis		11,124
Scenedesmus quadricauda		2,781
Scenedesmus incrassatula		7,416
Kirchneriella obesa		1,854
Naephrocytium sp.		927
Synedra ulna		9,270
Synedra sp.		1,854
Synedra delicatissima		5,562
Crucigenia apiculata	927	3,708
Tabellaria fenestrata	5,562	18,540
Melosira granulata	12,051	61,182
Melosira granulata v. augustissima	15,759	53,766
Dictyosphaerium pulchellum		2,781
Melosira binderana	927	6,489
Melosira sp. 1	927	7,416
Synedra acus		927
Tetraedron lunula		927
Aphanizomenon flos-aquae		927
Tetrastrum sp.		1,854
Fragilaria crotonensis	1,854	12,051
		907,000

Table 26

Phytoplankton

Station CP-3, Cook Plant
11 August 1969

Organism	No. of Colonies	Cells per Liter
Diatoma tenue v. elongatum		464
Chlamydomonas sp.		2,230
Mougeotia sp.		11,600
Oocystis sp.		8,816
Peridinium sp.		24,128
Cyclotella sp.		6,032
Scenedesmus quadricauda		928
Dinobryon divergens		6,960
Scenedesmus dimorphus		464
Ankistrodesmus falcatus		13,920
Golenkinia radiata		1,392
Fragilaria capucina	464	4,640
Gleocystis sp.		4,176
Quadrigula lacustris		464
Phormidium sp.		11,136
Actinastrum hantzschii		928
Ulothrix sp.		1,392
Nitzschia sp.		464
Tabellaria fenestrata		3,712
Anabaena sp.		464
Cryptomonas sp.		464
Synedra sp.		928
Synedra delicatissima		464
Tetraedron minimum		464
Fragilaria crotonensis	928	6,496
		113,000

Radiological Analyses

The following reports by Charles C. Kidd present a part of the studies of accumulation of radionuclides in the food chain, which have been carried on with funds from Indiana and Michigan Electric Company and from Toledo Edison.

Other studies, similarly supported are incorporated in a PhD thesis by Kidd which should be completed in the near future.

These reports by Kidd have just recently been received.

J. C. Ayers

RADIOLOGICAL HEALTH RESEARCH

PROGRESS REPORT

"THE ACCUMULATION OF RADIONUCLIDES BY PONTOPOREIA AFFINIS"

Submitted by, CHARLES C. KIDD

INTRODUCTION

Earlier experiments conducted by the writer during the period 1 Aug. 1968 thru 31 Oct. 1968 were designed to reveal the ability of the amphipod, *Pontoporeia affinis*, to accumulate radioactive elements in solution. In these experiments the amphipods were exposed to waste waters from a nuclear fuel reprocessing plant and a nuclear power reactor. These wastes contained significant quantities of radioactive zinc, zirconium, ruthenium, barium and cesium. Results of these experiments indicated that the organism only demonstrated an affinity for zinc as indicated by the accumulation of zinc-65. The concentration of radioactive zinc in the amphipods was approximately 250 times greater than the concentration of the isotope in solution after a 3-day exposure period. In order to confirm this observation, and to measure the ability of *Pontoporeia* to accumulate other radioactive elements the experiments described in this report were conducted. Some of the radioactive elements used in these experiments are peculiar to waste from nuclear facilities (activation products) and some may be present in the environment as a result of nuclear facilities operations or testing of nuclear devices (fission products). In some of the experiments the amphipods were exposed to radioactive elements in the absence of sediment from which they are known to obtain most of their food. By comparing experimental results of tests "with" and "without" sediment those accumulated isotopes involved in metabolic processes will be identified.

METHODS AND MATERIALS

The seven radioactive elements used in these experiments were cerium-144, manganese-54, zinc-65, cesium-137, zirconium-95, ruthenium-106 and strontium-90. A total of 14 plastic aquaria were used each containing 250 ml. of lake water. Thirty grams of sediment was added to 7 of the aquaria. Equal volumes of each solution containing a radioactive element were added to an aquarium without sediment and to one with sediment. Twelve amphipods were placed in each aquarium and all test animals were maintained at 10°C for 72 hours. At the end of this time all the water in the aquaria with sediment was slowly siphoned off into plastic cups. The amphipods were removed by flushing the sediment through a screen which retained them. Amphipods were removed from the aquaria without sediment with a small tea strainer. The 12 amphipods from each aquarium were divided into 3 groups of 4 animals each. The wet weight of each group of amphipods was determined immediately. All amphipods and water from tests involving gamma emitters with and without sediment were analysed for 200 minutes by a gamma spectrometer. Pontoporeia which had not been exposed to radioactive isotopes in the laboratory and were from the same area of Lake Michigan were also weighed and radioassayed. After adjusting each spectrum of gamma radioactivity obtained from analysis of the amphipods for the contribution of activity from unirradiated amphipods the specific activity, picocuries (pCi) per gram, was calculated for each isotope under both sets of test conditions. The residual activity per ml. in all tests waters was also calculated. Amphipods exposed to strontium-90 were wet-digested with nitric acid and the neutralized dry residue counted for 50 minutes in a Beckman Low Background Beta Counter. A sample of unirradiated amphipods was also analysed in this manner. Waters from the strontium tests were evaporated to dryness and analysed in the low background beta counter.

RESULTS

Tables #1 and #2 are "budgets" which reveal the fate of radionuclides used in each experiment. Significant percentages of all radioisotopes with the exception of ruthenium were removed by the amphipods in the tests without sediment.

The largest accumulation multiple, (pCi per gram/pCi per ml.) resulting from this experiment was 29 as observed for manganese and zinc. (See Table #3.) Results of the experiment with sediment revealed that significant percentages of manganese-54, zinc-65, strontium-90 were removed by the amphipods. Accumulation multiples for these isotopes were 29, 273 and 70, respectively. It was observed also that a large percent of each isotope added became associated with the sediment and thereby available to the amphipods.

CONCLUSIONS

The results of the experiments described above indicate that *Pontoporeia affinis* has a greater affinity for zinc than any other isotope tested. It is also concluded the accumulation of strontium and zinc are enhanced by their availability in the sediment and that their accumulation involves metabolic processes.

Experiments will be initiated shortly to determine maximum accumulation multiples for radioactive strontium, zinc and manganese. Strontium-85, a gamma emitter, will be used in these experiments to permit the simultaneous measurement of radioactivity due to all three isotopes by gamma spectrometry. Having reached a maximum specific activity test organisms will be placed in aquaria containing no added radionuclides. The loss of activity in time will permit the calculation of the effective and biological half-lives of each radioisotope in the amphipod.

Table 1

Budget of Radionuclides for 72 Hours Laboratory Uptake Experiment Without Sediment

Radionuclide	Total activity added (pCi)	Activity remaining in solution (pCi)	Activity removed by Amphipods (pCi)	Percent removal
$Ce^{144}-Pr^{144}$	820	818	2	0.24%
Mn^{54}	214,000	212,843	1,157	0.54%
Zn^{65}	32,300	32,132	168	0.52%
Cs^{137}	1,745	1,736	9	0.52%
$Zr^{95}-Nb^{95}$	2,950	2,948	2	0.06%
$Ru^{106}-Rh^{106}$	30,600	>30,599	<1	<0.003%
$Sr^{90}-Y^{90}$	1,825	1,819	6	0.33%

Table 2

Budget of Radionuclides for 72 Hour Laboratory Uptake-Experiment With Sediment

Radionuclide	Total activity added (pCi)	Activity remaining in solution (pCi)	Activity removed by sediment (pCi)	Activity removed by sediment % Removal	Activity removed by Amphipods (pCi)	Activity removed by Amphipods % Removal
Ce^{144}-Pr^{144}	820	338	482	58.80%	0	0
Mn^{54}	214,000	20,942	182,937	85.44%	121	0.06%
Zn^{65}	32,300	1,696	30,541	94.50%	63	0.20%
Cs^{137}	1,745	280	1,465	84.00%	0	0
Zr^{95}-Nb^{95}	2,950	374	2,576	87.30%	0	0
Ru^{106}-Rh^{106}	30,600	6,833	23,764	77.61%	3	0.01%
Sr^{90}-Y^{90}	1,825	765	1,052	57.60%	8	0.50%

Table 3

Specific Activities and Accumulation Multiples in *Pontoporeia affinis* Resulting from 72 Hour Laboratory Uptake Experiments

Radionuclide	Specific Activity (pCi/gram) Without Sed.	With Sed.	Accumulation Multiple ($\frac{pCi/gram}{pCi/ml.}$) Without Sed.	With Sed.
Ce^{144}-Pr^{144}	46	0	20	0
Mn^{54}	24,450	3,641	29	29
Zn^{65}	3,730	1,854	29	273
Cs^{137}	155	0	22	0
Zr^{95}-Nb^{95}	109	0	9	0
Ru^{106}-Rh^{106}	6	71	0.8	3
Sr^{90}-Y^{90}	122	212	17	70

Accumulation of Radioactive Isotopes by
Lake Erie Benthic Worms

24 July 1969

ISOTOPE	SAMPLE #	TYPE	WET WT. (g)	7-DAY ACTIVITY		CONCENTRATION FACTOR
				In water	In worms	
Mn^{54}	1	Chironominae	0.112	4.18 $\frac{cpm}{ml}$	411 $\frac{cpm}{g}$	98.3
	2	Oligochaetes	0.129		388 "	93.0
Cs^{137}	3	Chiron.	0.259	3.95 $\frac{cpm}{ml}$	467 $\frac{cpm}{g}$	118
	4	Oligo.	0.201		323 "	81.7
Zn^{65}	5	Chiron.	0.039	2.30 $\frac{cpm}{ml}$	1692 $\frac{cpm}{g}$	736
	6	Oligo.	0.176		369 "	160
Sr^{85}	7	Chiron.	----	----	----	----
	8	Oligo.	0.071	30.2 $\frac{cpm}{ml}$	676 $\frac{cpm}{g}$	22.4

ACCUMULATION OF RADIOISOTOPES BY FRESHWATER CLAMS (LAKE ERIE)

C. Kidd 24 July 1969 72-Hour Test

ISOTOPE	SAMPLE	SOFT TISSUE WET WEIGHT	TOT. ACTIVITY IN SOFT TISSUE (cpm)	(cpm/g) CONC. OF ACTIVITY IN SOFT TISSUE	(cpm/ml) ACT. CONC. IN WATER	CONC. FACTOR IN SOFT TISSUE	WEIGHT OF SHELL	TOT. ACT. IN SHELL (cpm)	CONC. OF ACTIVITY IN SHELL (cpm/g)	CONC. FACTOR IN SHELL
Sr^{85}	8	32.1	387	12.1	19.9	0.61	30.5	533	17.5	0.88
	9	28.1	309	11.0		0.55	7.20	501	69.5	3.56
	10	32.7	139	4.25		0.21	8.30	444	53.4	2.68
	13	87.9	688	7.83		0.39	61.9	878	14.2	0.71
Cs^{137}	8	32.1	536	16.7	6.90	2.42	30.5	2011	65.9	9.55
	9	28.1	1095	39.0		5.65	7.20	1774	246	35.7
	10	32.7	1675	5.18		0.75	8.30	1164	140	20.2
	13	87.9	1428	16.2		2.34	61.9	2441	39.4	5.7
Mn^{54}	8	32.1	209	6.51	3.30	1.97	30.5	304	9.96	3.02
	9	28.1	90.0	3.20		0.97	7.20	377	52.4	15.9
	10	32.7	0	0		0	8.30	420	506	153
	13	87.9	17.0	0.19		0.06	61.9	542	8.75	2.65
Zn^{65}	8	32.1	151	4.70	3.23	1.45	30.5	209	6.85	2.12
	9	28.1	0	0		0	7.20	322	44.7	13.8
	10	32.7	2.00	0.06		0.02	8.30	288	34.6	10.7
	13	87.9	30.0	0.34		0.11	61.9	433	6.99	2.16

RADIOLOGICAL ANALYSIS OF
SEDIMENT SAMPLES - C. Kidd
July 24, 1969

SAMPLE NO.	SAMPLE STATION	WET WEIGHT OF SOIL SAMPLE (g)	DEPTH	GROSS γ ACTIVITY		Cs^{137} ACTIVITY	
				cpm/g	pCi/g	cpm/g	pCi/g
1	LLP-15	239.3	7 m	1.68	21.2	0.33	3.25
2	FP-9	352.1		0.68	8.57	0.07	0.69
3	FP-6	316.7		0.65	8.19	0.07	0.69
4	FP-4	432.2		0.75	9.45	0.09	0.89
5	FP-10	574.4		0.62	7.31	0.09	0.89
6	FP-8	213.5		1.91	24.1	0.43	0.42
7	FP-1	229.5		1.15	14.5	0.18	1.77
8	FP-7	131.8		1.57	19.8	0.17	1.68
9	FP-12	394.8		0.97	12.2	0.18	1.77
10	FP-3	238.8		1.79	22.6	0.40	3.94
11	FP-2	209.4		1.43	18.0	0.25	2.47
12	FP-5	205.1		1.10	13.9	0.15	1.48
13	FP-11	345.8		1.26	15.9	0.29	2.86
14	LPP-13	208.0	2 m	1.09	13.7	0.19	1.87
15	LPP-10	136.5	3 m	1.75	22.0	0.30	2.96
16	LPP-1	164.9	5.5 m	1.46	18.4	0.14	1.38
17	LPP-6	222.3	1.5 m	1.11	14.0	0.09	0.89
18	LPP-4	175.8	5.5 m	1.44	18.1	0.18	1.77
19	LPP-7	142.2	5 m	0.54	6.80	0.14	1.38
20	LPP-9	139.2	1.5 m	0.83	10.5	0.15	1.48
21	LPP-2	181.5	5 m	1.55	19.5	0.19	1.87
22	LPP-3	157.5	1.5 m	1.29	16.3	0.12	1.18

AVE. LPP - STATION: GROSS γ - ACTIVITY = 16.1 $\frac{pCi}{g}$

Cs^{137} ACTIVITY = 1.80 pCi/g

AVE. FP - STATION: GROSS γ - ACTIVITY = 14.6 pCi/g

Cs^{137} ACTIVITY = 1.96 pCi/g

REPORT OF RADIOASSAY OF FIELD SAMPLES

Submitted by, CHARLES C. KIDD

INTRODUCTION

Radioassay of macrobenthos samples collected in July, 1968 during an environmental survey of Lake Michigan in the vicinity of The Big Rock Nuclear Power Plant indicated that levels of gross beta and gamma radioactivity in *Pontoporeia affinis* might possibly reflect the influence of radionuclides released in the waste from the plant. However, the samples taken at that time did not contain many amphipods. Moreover, there were insufficient sampling locations to discern any pattern or trend in levels of radioactivity. On October 18, 1968 the writer returned to the area and working off The Great Lakes Research Division's ship "The Mysis", obtained more benthos samples from nine sampling points (see figures #1 and #2) in the vicinity of The Big Rock Nuclear Power Plant. The objective of the study described in this report is to detect any pattern in the distribution of radioactivity as results from the radioassay of the amphipods collected. The degree to which *Pontoporeia affinis* responds to the low levels of radioactivity encountered in the study area is reflective of their usefulness as biological indicators of environmental radioactivity.

METHODS AND MATERIALS

Bottom samples were taken with a Ponar Dredge. The dredge was lowered four times at each sampling point. This represented a sampling area of approximately 0.25 square meters. Sampling depth ranged from 70 feet to 300 feet. All samples were washed free of mud and put in 1-pint Mason Jars. A small amount of Formalin was added to preserve each sample. In the laboratory the *Pontoporeia* were picked from each sample and weighed. They were then wet digested in nitric acid. The neutralized residue was dried on stainless steel planchets and analysed for 200 minutes in a gamma spectrometer. The samples were also analysed for 200 minutes in The Beckman Low-Background Beta Counter. The average gamma detection efficiency for the 5 inch NaI(Tl) crystal and multichannel analyser combination is 20% over the energy range of 0.02 to 2.0 million electron volts. This value was used to calculate the gross gamma radioactivity as indicated by the 200 minute count. The efficiency of the low-background beta counter was 42% for gross beta counting. Gross gamma and beta radioactivity was calculated and recorded as picocuries per gram (pCi/gram) of amphipod (see table #1).

RESULTS

Gross beta radioactivity in the amphipods ranged from 0.55 to 10.93 pCi/gram. The range of gross gamma radioactivity in the amphipods was 4.07 to 40.20 pCi/gram. When gross beta and gamma activities were plotted on a scaled map of the study area the patterns of radioactivity shown in figures #1 and #2 were drawn.

CONCLUSIONS

The patterns of both types of radioactivity reveal the influence of the nuclear power plant on levels of environmental radioactivity. Water from an area near the discharge channel of the power plant was previously assayed and contained 54 pCi per liter, gross gamma activity. Gross gamma activity in *P. affinis* used in this experiment apparently exceeds the concentration in the water tested by from 76 to 745 times. More water samples from the study area are being analysed for gross radioactivity. The results of these tests will be compared with levels of radioactivity reported for the study area prior to plant operation.

Table 1

Results of Radioassay of _Pontoporeia_ _affinis_ from Benthos Samples Taken in the Vicinity of The Big Rock Nuclear Power Plant

Sampling Point*	Wet Weight of Sample (Grams)	Radioactivity (pCi/gram) Gross Beta	Gross Gamma
1	0.89	1.66	7.83
2	1.79	1.27	4.20
3	1.22	1.44	4.91
4	1.65	1.25	4.07
5	1.32	1.69	7.05
6	0.74	1.10	14.69
7	2.32	0.55	4.86
8	0.10	3.44	40.20
9	0.79	10.93	9.86

*See Figures 1 & 2 for location of sampling points.

FIGURE #1 ISO-ACTIVITY CONTOURS, GROSS GAMMA RADIOACTIVITY, (pCi/gram) in PONTOPORIEA AFFINIS
BENTHOS SAMPLING POINTS — ●

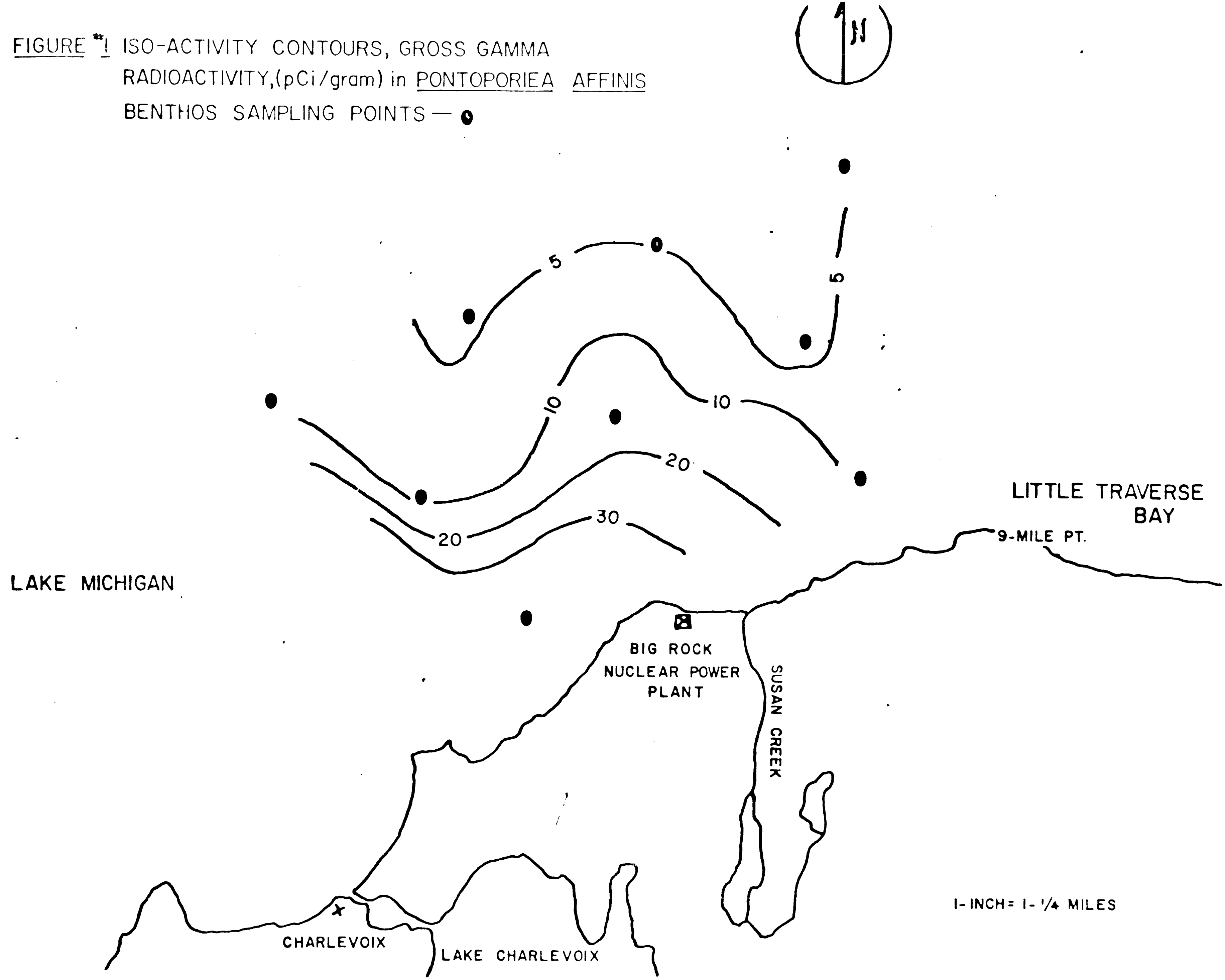


FIGURE #2 ISO-ACTIVITY CONTOURS, GROSS BETA RADIOACTIVITY, (p Ci/gram) in PONTOPORIEA AFFINIS
BENTHOS SAMPLING POINTS — ●